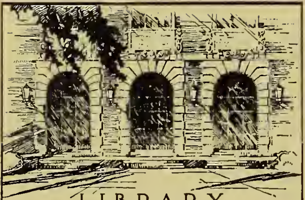

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Antenna Laboratory

Technical Report No. 57

POLYGONAL SPIRAL ANTENNAS

by

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and

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ABSTRACT

By relaxing the similarity condition on the angular structures, a class of modified angular structures when used as antennas are shown to have frequency independent performances. The class of log-periodic antennas belongs to the modified conical structure which is a special case of the general angular structure. The general angular structure can be described by log-spiral curves which lead to the design of log-spiral antennas. In this report, modifications are made on the general angular structures with the view of obtaining a larger class of frequency independent antenna design. The measurements taken on some of the structures indeed give the desirable results.

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1. INTRODUCTION

The design of broadband antennas is one of the major tasks for an antenna designer. Its theory has been advanced remarkably by the introduction of the angle concept by Rumsey[1] and the principle of logarithmic periodicity by DuHamel[2].

The angle concept is a consequence deduced from the theory of similtude and sealing, and it leads to the investigation of angular structures. The idea of making antennas to possess electrical properties which will repeat periodically with the logarithm of the frequency was arrived at in considering the convergence problem of the finite angular structures. Since all angular structures are necessarily of infinite extent, the convergence problem of the electrical properties of the finite structure toward those of the infinite structure must be overcome. Experiments have shown that this can be accomplished by introducing certain periodic discontinuities in some finite angular structures. These ideas have since stimulated a large amount of activities in the antenna field.

Dyson's log-spiral antennas[3] and then Isbell's log-periodic dipole arrays[4] were pioneer works in bringing two different types of frequency independent antennas into practice. The term "frequency independent" shall be used to indicate that antennas of this class can be designed in such a way that they will perform with practically constant characteristics -- input impedances and radiation patterns, for any desired bandwidth, anywhere in the practical frequency spectrum. It is now well known that log-spiral antennas have a circularly polarized, frequency independent, radiation field while log-periodic dipole antennas radiate linearly polarized, frequency independent, far field patterns, and their impedance characteristics both remain practically constant within the designed bandwidth. Following these discoveries, effort has been directed toward practical applications of these two types of frequency independent antennas. The multi-arm log-spiral antennas were investigated by Mayes and Dyson[5,6]. They demonstrated that an omnidirectional pattern could be obtained with log-spiral antennas by using symmetrically spaced multiple arms. Recently Dyson[7] has considered the coupling effect between log-spiral antennas arranged in various arrays. Various designs and applications of log-periodic antennas have been investigated by Mayes[8], Carrell[9]

DuHamel et al.[10,11,12,13] A bibliography of articles on wideband and frequency independent antennas has been presented by Dyson.[14]

The theoretical analysis of these frequency independent antennas has also been pursued by many authors. Mast[15] has solved the static problem of the log-spiral structure. Rumsey,[16] in solving the sheath model of the log-spiral structure, has successfully transformed the exterior vector problem into scalar problems by decomposing the field into right-hand and left-hand circularly polarized components. Copeland[17] and Lee[18] assumed the current distribution along the antenna arm in analyzing the radiation field of non-planar spiral antennas. Carrel[9] analyzed the log-periodic dipole structure based on circuit theory. Generally speaking, work still remains to be done to solve the theoretical problem of above mentioned frequency independent antennas.

The lack of the complete theoretical solution on the problem of frequency independent antennas does not prevent an antenna engineer from making progress in the practical designs. Those ideas which were impetus to the birth of the frequency independent antennas can still be used as guiding principles for the design and the experimental method serves as a practical way of verification. Through an accumulation of workable structures, one may gain a better insight to the frequency independent operation. These outlooks were motivations for the present investigation on the frequency independent antennas.

It is the purpose of this report to point out that there is a group of approximate log-spiral antennas which are also capable of frequency independent performances, in the above defined sense. The basic consideration which leads to this approximation is the relation of the continual similarity condition and the log-spiral configuration is thus approximated by a set of connected and proportioned segments. They are called polygonal spiral antennas. Several polygonal spiral antennas have been constructed and their characteristics investigated. Experimental results indicate that their behaviors are very similar to that of the corresponding log-spiral antennas.

Both polygonal spiral antennas and other log-periodic rectilinear structures have only discrete similarity in contrast to the continual similarity for the log-spiral structures.

2. THE DESIGN OF FREQUENCY INDEPENDENT ANTENNAS

We shall try to relate some basic concepts and guiding principles useful in making the design of frequency independent antennas so as to give a better insight of the theory.

2.1 Similar Figures and the Electrodynamical Similitude

In the plane geometry, similar polygons are defined as figures having all corresponding angles equal and all corresponding line segments proportional. Extending this notion to more general entities, similar surfaces are surfaces which can be made to correspond point to point in such a way that the distance between any two points on one surface is always the same multiple of the distance between two corresponding points on the other. The property of being similar is called similarity.

The general transformation of similarity is the product of the general Euclidean transformation composed possibly of a translation and a rotation, and a radial transformation. A two dimensional radial transformation is a transformation expressed by the equations

$$x' = \tau x, \qquad y' = \tau y \tag{1}$$

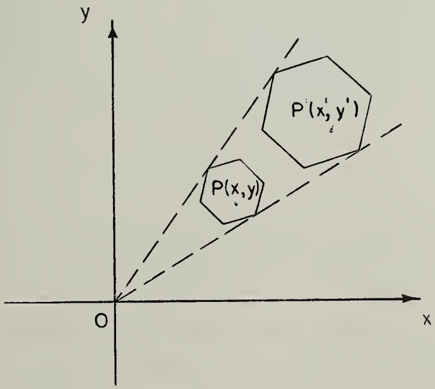

Figure 1. A Radial Transformation

For an example, P and P$'$ in Figure 1 are related by the radial transformation. The real number τ is the ratio of similitude and the origin 0 is called the center of similitude.

Analytically, the general transformation of similarity can therefore be expressed by the equations

$$\begin{aligned} x' &= \tau(x \cos \theta - y \sin \theta + a) \\ y' &= \tau(x \sin \theta + y \cos \theta + b) \end{aligned} \tag{2}$$

for two-dimensional figures. The similarity transformation of figures in the space can also be expressed analytically.

With the above definition of similar figures, one can develop a theory of linear modeling for electromagnnetic problems, usually referred to as electrodynamical similitude. To be specific, the term "similar electromagnetic boundary value problems" will be used to imply the relation between two antenna problems in which the electrical properties of the modeled antenna are the same as that of the original except for a change in scale.

Through dimensional analysis of Maxwell's equations, it is readily shown that the similitude conditions imposed on the similar problems are[19]

$$f_\tau = f_1/\tau \tag{3}$$

$$\mu_\tau \epsilon_\tau = \mu_1 \epsilon_1 \tag{4}$$

$$\mu_\tau \sigma_\tau = \mu_1 \sigma_1/\tau \tag{5}$$

where f_τ, μ_τ, ϵ_τ and σ_τ are the operating frequency, the permeability, the permitivity and the conductivity of the modeled antenna system respectively, while f_1, μ_1, ϵ_1 and σ_1 are those of the original antenna system.

It is seen that if μ and ϵ are kept constant, doubling of the size of the antenna requires that the operating frequency and the conductivity of the antenna structure both be halved, while shrinking of the size of the antenna into a half requires that the operating frequency and the conductivity of the antenna structure both be doubled. Scaling of the conductivity however, causes a great inconvenience in practical designs. Fortunately, in most cases, if the conductivity is high, it can be kept unchanged and the linear modeling of antennas will still hold approximately. This may thus be termed as the approximate linear modeling of antenna problems, and its theory involves the finding of similar figures.

Belyea, Low and Segel[20] reported to have met some difficulties in scaling a certain aircraft for an x-band radar cross-section experiment with the linear modeling theory. They have developed a non-linear modeling theory for the electromagnetic problem and others.

2.2 Self Similar Figures

Figures with the whole similar to its part are called self-similar figures. Usually, many self-similar figures may be drawn for a given figure. For example, the following shaded triangles are similar to their original triangles.

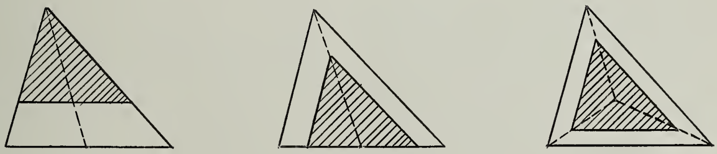

Figure 2. Self-Similar Figures

For every pair of similar figures there is a ratio of similitude or the scaling parameter τ. For a self-similar figure, the set of similar figures can be transformed into each other by a similarity transformation with an associated scaling parameter τ. Since a general similarity transformation, as indicated in last section, is the product of the general rigid motion and a radial transformation, it follows that for the self-similar figures, the similarity transformation contains only the product of the rotation and a radial transformation.

It is required by the theory of similitude that in order to achieve the true frequency independent operation, the configuration of the antenna must be a self-similar figure with $0 < \tau < \infty$. This implies a continuous similarity. An infinite conical configuration is an example of these structures. The general structure of this type was found by Rumsey[1] to be that described by the log-spiral curves.

$$r = r_o e^{a\varphi} \tag{6}$$

where a and r_o are constants. For the conical structures, the similarity transformation involves only a radial transformation while for the log-spiral structures, the similarity transformation contains both the expansion and the rotation and they are related by

$$\theta = \ln \tau / a \tag{7}$$

where θ is the angle of rotation.

When the admissible values of τ for the similarity transformation form a discrete set (τ_n), then the self-similar figure possesses only a discrete similarity. The log-periodic structures belong to this class and have $\tau_n = \tau^n$, n = integers. We shall show that the polygonal spiral structures are also self-similar figures with discrete similarity and a construction method will be given. Both the log-periodic structures and the polygonal spiral structures are modified angular structures.

2.3 The Convergence Problem of the Angular Structure as a Frequency Independent Antenna and the Modified Angular Structures.

All angular structures are infinite extent. To be used as antennas, they must be truncated. The amount of end effects due to the truncation serves as another criterion for being a frequency independent antenna besides the similarity condition. It is known that not all angular structures lead to the frequency independent antenna design; the log-spiral structures were shown experimentally to have only negligible end effects under suitable design, while the radiation of the biconical structures can be attributed to the end effect. This implies that when the similarity condition is insisted, the design of the frequency independent antennas is restricted to a special angular structure -- log-spiral antennas.

It has also been shown experimentally that some angular structures which can not be used for the frequency independent antenna design under the strict similarity condition become useful structures when the similarity condition is relaxed in a certain way. The log-periodic structures are examples of this situation. They all belong to modified angular structures -- angular structures with periodic discontinuities.

Based on the principle of scaling and in view of above experimental results, one realizes that much flexibility could be gained in the design of frequency independent antennas (or rigorously speaking, approximate frequency independent antennas) by relaxing the similarity condition. As the log-periodic structures are derived from the conical angular structures, we shall demonstrate a way of relaxing the similarity condition for the log-spiral structures.

3. POLYGONAL SPIRAL ANTENNAS

The polygonal spiral antenna was developed by relaxing the continuous similarity condition of the log-spiral structures. First a generalized definition of spiral structure will be given and then certain similarity condition imposed so as to give a polygonal spiral structure which inscribes a log-spiral curve.

3.1 A Definition of Spirals

A spiral curve can be defined as a line which, starting from a point of origin, which is called the pole, continually diminishes in curvature as it recedes from that point, in other words, the radius of curvature continually increases. A log-spiral is such a curve that the arc intercepted between the pole and any other point whatsoever on the curve is always similar to itself. Therefore a log-spiral curve is self-similar with continuous similarity.

To modify the structure by replacing the curved structure with straight elements, the rectilinear spiral curve is constructed as follows: from some starting point, or the pole, a straight is drawn in a given direction to a definite point P_1 at a fixed distance l_1 and changing the direction, a second straight line with length l_2 is drawn to a point P_2. From P_2 a third line is started in a different direction from that of the second line. With length l_3, a point P_3 is reached. The process can be continued indefinitely as shown in the following figure.

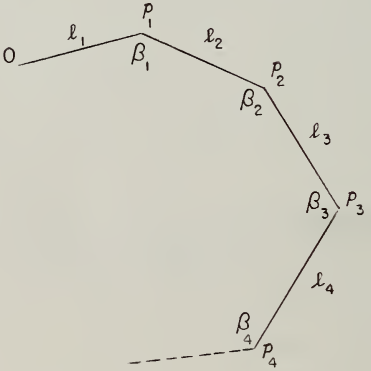

Figure 3. A Rectilinear Spiral

Using this definition of rectilinear spiral structures as a construction principle in relaxing the continuous similarity condition of the log-spiral structure, a discrete similarity property can be obtained for these structures by requiring

$$\frac{l_n}{l_{n+1}} = \tau_n = \tau^n = \left(\frac{l_1}{l_2}\right)^n \tag{8}$$

$$\beta_1 = \beta_2 = \beta_3 = \ldots = \beta \tag{9}$$

It is seen that if $\tau = 1$, the structure is a regular polygon. In which case, the angle β is determined by the number of sides of the polygon m

$$\beta = \frac{(m-2)\pi}{m} \tag{10}$$

If $\tau < 1$, it becomes a converging polygonal spiral while $\tau > 1$ gives a diverging polygonal spiral. It is shown that each of these polygonal spiral structures, a log-spiral curve can be found to circumscribe it.

3.2 Polygonal Spirals

The construction of polygonal spirals was given in the preceeding section. Its relation to log-spiral structures shall be pointed out presently.

A proposition on the characteristics of log-spiral curves can be stated as follows.

Proposition: In a log-spiral, the polar radii of points whose vectorial angles are in arithmetic progression are themselves in geometric progression.

If the above said points are connected, then a polygonal spiral structure is obtained, as shown in Figure 4. A corollary follows from the above proposition. The sides of the polygonal spiral are also in geometric progression.

In Figure 4

$$\varphi_1 = \varphi_2 = \varphi_3 = \varphi_4 = \ldots = \varphi_o$$

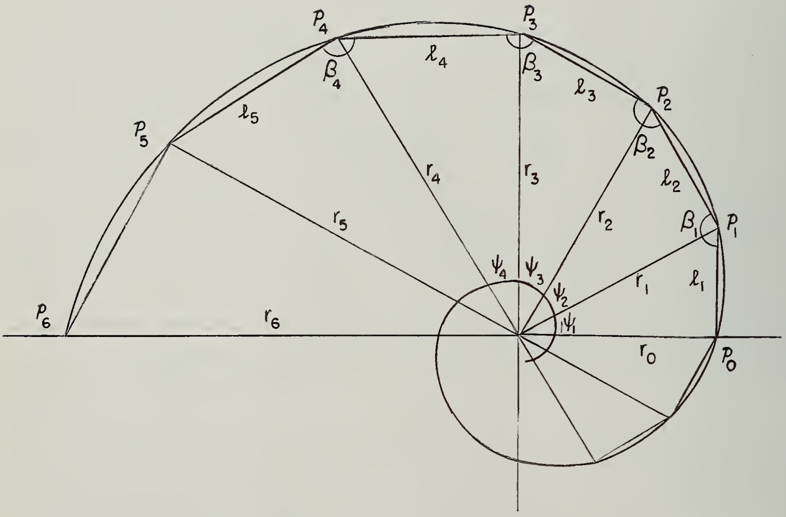

Figure 4. A Log-Spiral Curve and a Polygonal Spiral Structure

and

$$r_1 = r_o\, e^{a\varphi_o}, \qquad r_2 = r_1\, e^{a\varphi_o}, \qquad \ldots$$

Therefore

$$\frac{r_1}{r_o} = \frac{r_2}{r_1} = \ldots = e^{a\varphi_o} \tag{11}$$

The side of the polygonal spiral can be expressed as

$$l_1 = r_o\sqrt{1 + e^{2a\varphi_o} - 2e^{a\varphi_o}\cos\varphi_o} = r_o\, t$$

$$l_2 = r_1\, t$$

etc.

hence we also have

$$\frac{l_2}{l_1} = \frac{l_3}{l_2} = \ldots = \frac{r_1}{r_o} = e^{a\varphi_o} \tag{12}$$

Thus from these we obtain

$$\tau = e^{a\varphi_o} \tag{13}$$

and

$$\beta = \pi - \varphi_o$$

Several particular polygonal spiral structures, a triangular spiral, a rectangular spiral and a pentagonal spiral are shown respectively in Figures 5, 6, and 7.

3.3 Zigzag Structures

Under the general definition, the rectilinear spiral structures also include the biangular configurations as a special case. To satisfy the self-similarity condition we impose the following conditions for these structures.

$$\frac{l_1}{l_3} = \frac{l_2}{l_4} = \ldots = \tau \tag{14}$$

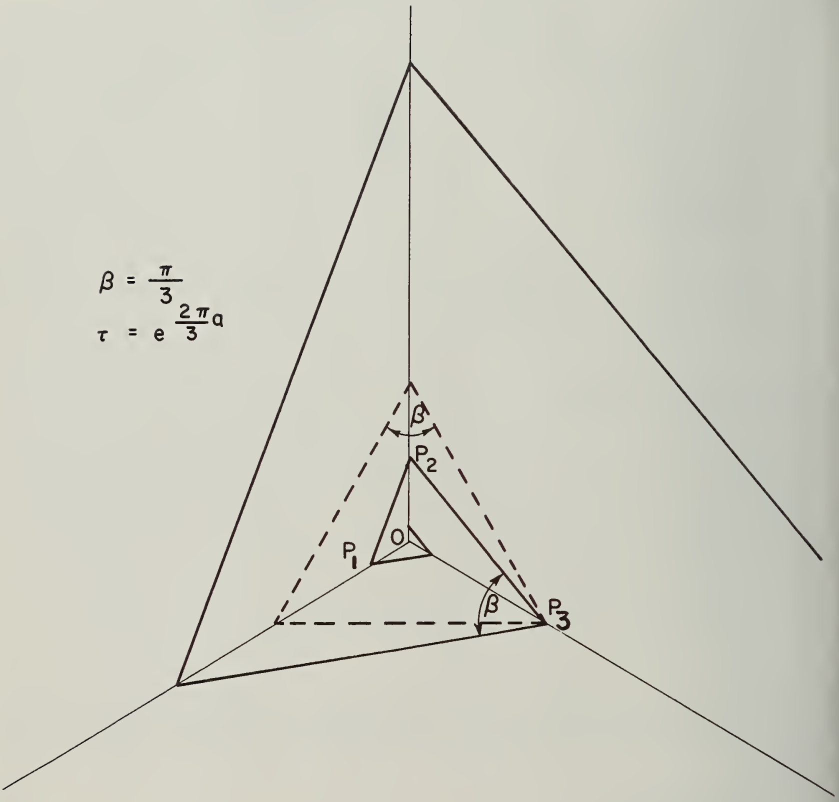

Figure 5. A Triangular Spiral

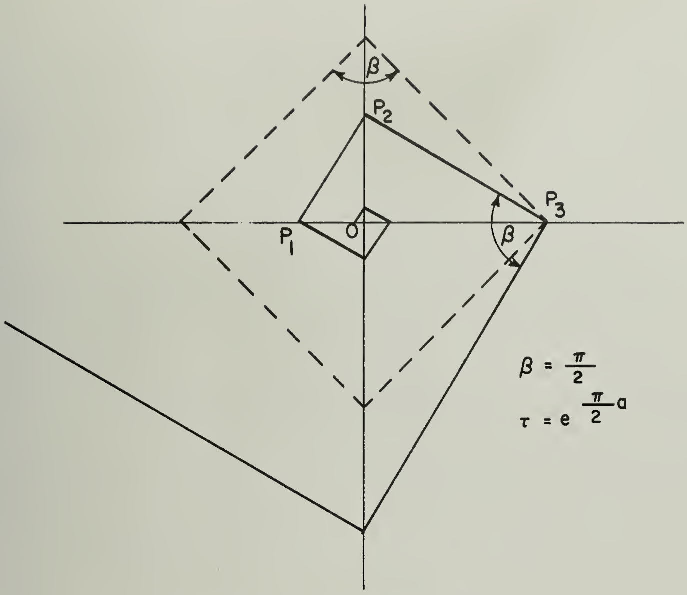

Figure 6. A Rectangular Spiral

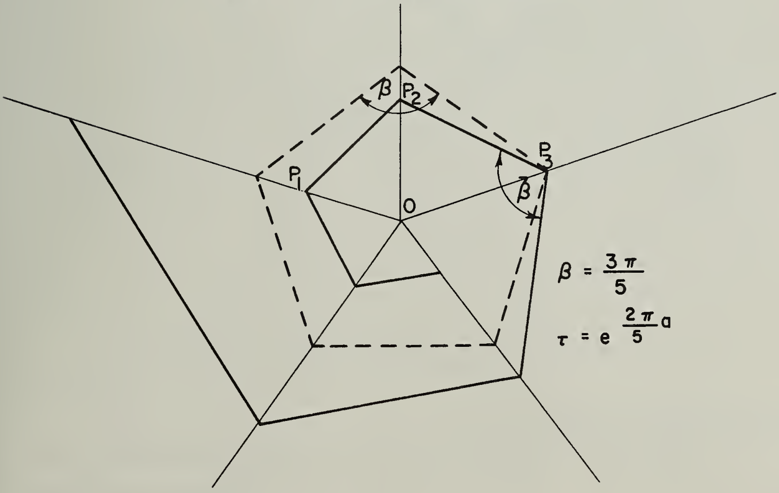

Figure 7. A Pentagonal Spiral

$$\beta_1 = \beta_2' = \beta_3 = \beta_4' = \cdots \tag{15}$$

where

$$\beta_2' = 2\pi - \beta_2$$

$$\beta_4' = 2\pi - \beta_4$$

---

hence they become the log periodic Zigzag configurations.

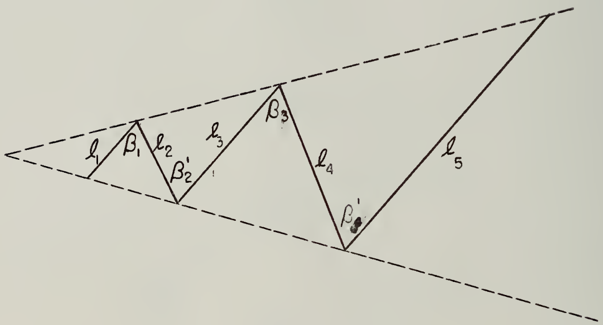

Figure 8. A Log-Periodic Zigzag Structure

3.4 The Scaling Parameter

It is seen that a polygonal spiral is uniquely determined by specifying the parameters β and τ. Their relations to the circumscribing log-spiral curve is given by

$$\tau = e^{(\pi-\beta)a} = e^{\frac{2\pi}{m}a} \qquad (16)$$

for a planar log-spiral

$$a = -1/\tan\alpha \qquad (17)$$

where α is the spiral angle, i.e., the angle between the inward radius vector and the tangential vector. For a conical log-spiral structure

$$a = -\sin\theta_o/\tan\alpha \qquad (18)$$

where θ_o is the half-cone angle. A conical rectangular spiral is shown in Figure 9 in comparison to a conical log-spiral structure. Note that in the case of polygonal spirals the spiral angle α is a variable.

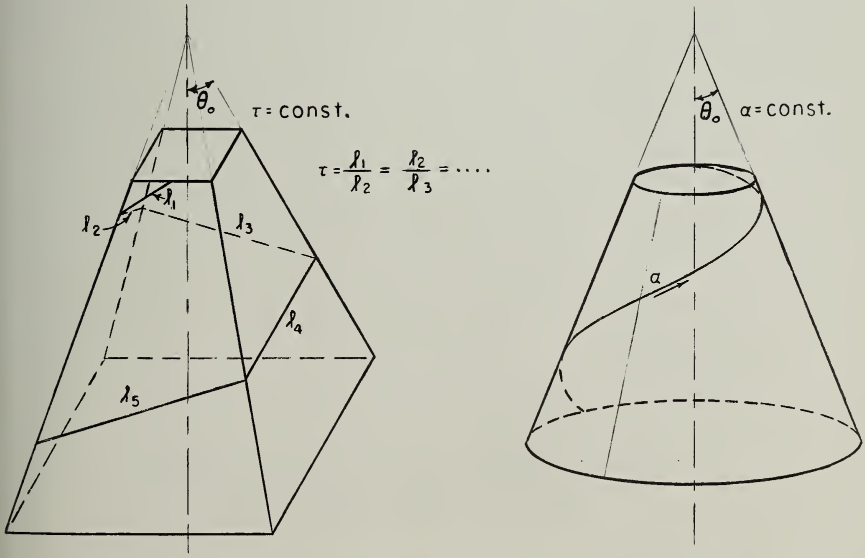

Figure 9. A Conical Rectangular Spiral and a Conical Log-Spiral

From Equations (16) and (18), the equivalent conical polygonal spiral can be determined for a given conical log spiral, i.e. for a given set of cone angle θ_o and spiral angle α, the scaling parameter τ is fixed for the polygonal spiral. Figure 10 gives the scaling parameters for a rectangular spiral related to its corresponding log-spiral structures. This shows the relationship between a conical rectangular spiral and a conical log-spiral. Similar relationships can be obtained for other polygonal spiral and their corresponding log-spirals. Figure 11 shows the scaling parameter of polygonal spirals of $m = 2, 3, 4, 5, 6$, for the spiral angle of the log-spiral $\alpha = 35^o, 70^o$ and 80^o.

These graphs serve as a mean in relating the operating characteristics of continuous self-similar structures to that of discrete ones. The design criterion expressed in terms of the scaling parameter τ for the log periodic structures can therefore be related to those criterions expressed in terms of the half-cone angle θ_o and the spiral angle α for the log-spiral structures.

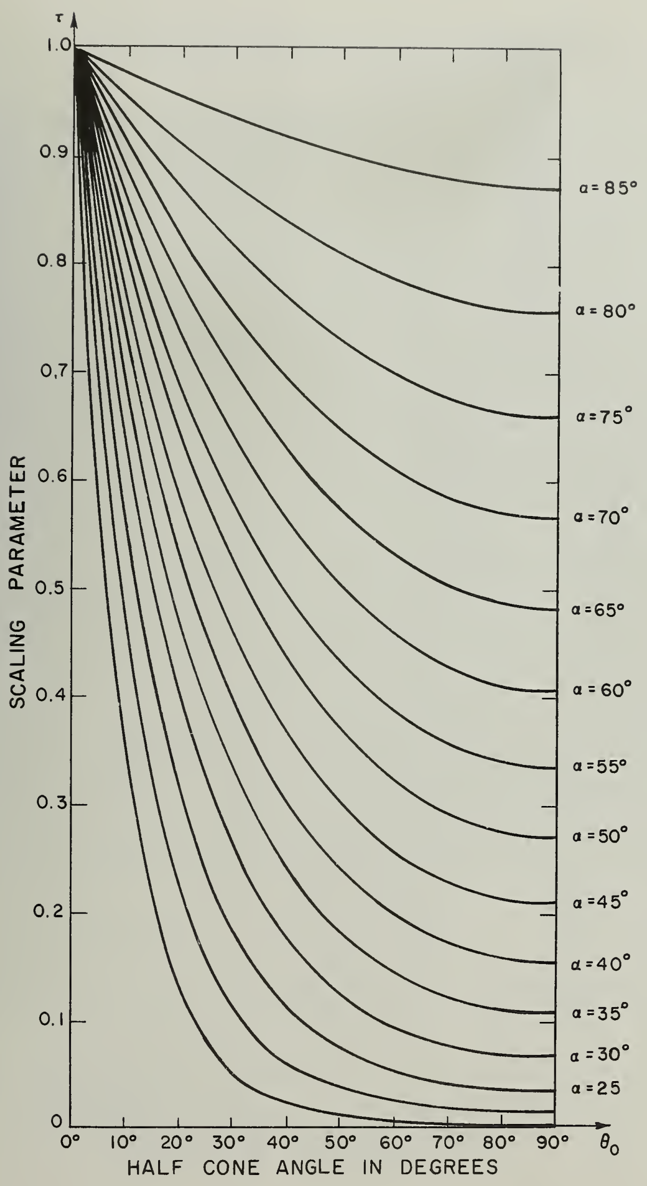

Figure 10. The Scaling Parameter of the Rectangular Spiral

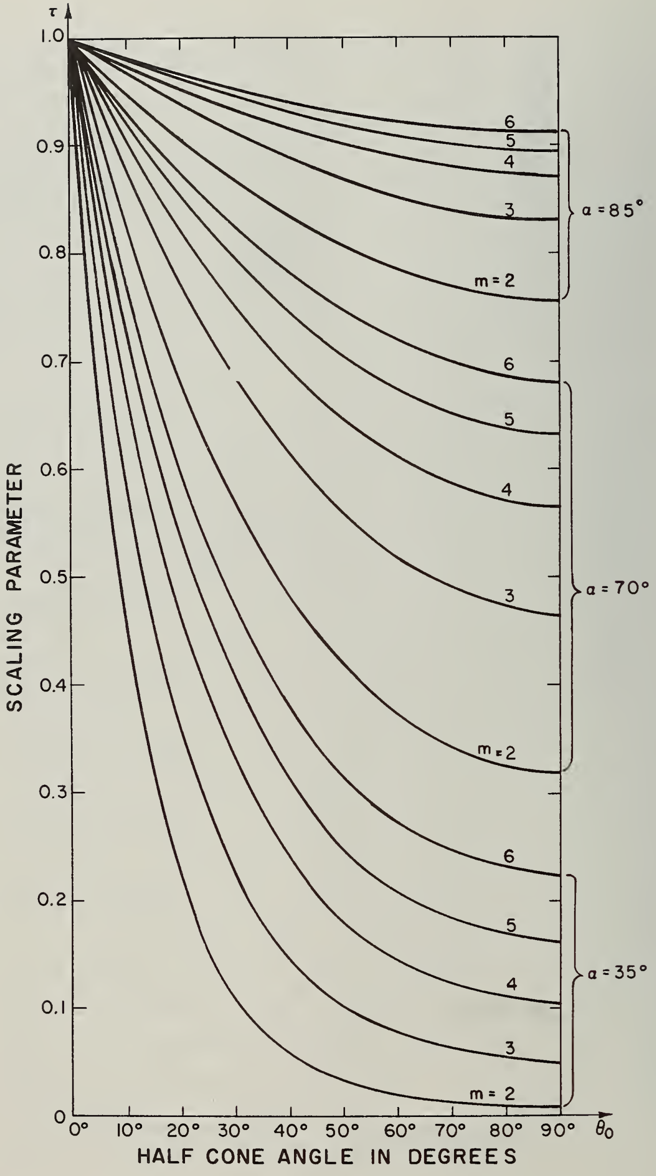

Figure 11. The Scaling Parameter of Polygonal Spirals for m = 2, 3, 4, 5, 6

4. EXPERIMENTAL METHOD AND MEASUREMENT RESULTS

4.1 Experimental Method

The polygonal spiral structures, discussed in Chapter 3, when used as antennas, will be referred to as the polygonal spiral antennas. For convenience of the feeding, m is restricted to be an even integer. When m = 2, it becomes a bifilar log-periodic zigzag antenna.

Based on the property of self-similarity, we infer that the polygonal spiral antennas can be designed to give frequency independent performances. Evidently, for large enough m its behavior will approach that of the corresponding log-spiral antenna. The practical problem is, therefore, to determine the number of sides of the polygonal spiral antenna which behaves practically like a log-spiral antenna. This was our endeavor and we have shown experimentally, that a rectangular spiral antenna is already a good approximation to its log-spiral counterpart.

In order to compare the operation characteristics between that of the rectangular spiral antenna and that of the corresponding log-spiral antenna, six different rectangular spiral antennas were constructed and tested. The parameters of these structures were chosen to give a comparison with some typical characteristics of the log-spiral structures.

It has been shown experimentally by Dyson[21] that the pattern beam width of the radiation field of a two arm conical log-spiral antenna, although frequency independent, is a function of the spiral angle α. In general, it may be stated that the beam width increases as the spiral angle α decreases. The numerical results, due to Dyson, can be shown as follows:

α	82°	73°	60°	45°
BW	60°-70°	70°-80°	120°-150°	180°-200°

where BW is the half power beam width of the radiation pattern. He also observed that the log-spiral structure can be approximated by the wire version only when the antenna is relatively tightly spiraled, say $\alpha > 60^\circ$. As the angle α is decreased to the neighborhood of 45° to 50° marked pattern changes occur for the wire approximation, including a multilobing of the main beam and large radiation off the base of the cone.

For these reasons, the following parameters for the testing antennas were chosen. They are listed together with the corresponding scaling parameter τ.

(a) $\theta_o = 7.5^\circ$

α	45°	60°	73°
τ	0.814	0.892	0.94

(b) $\theta_o = 10^\circ$

α	45°	60°	73°
τ	0.76	0.858	0.92

One of the structures, $\theta_o = 7.5^\circ$ $\alpha = 73^\circ$ is shown in Figure 12 and its corresponding wire version log-spiral structure is shown in Figure 13. RG8/U cables were used for these antenna structures.

The measured results on the radiation patterns and the input impedances of these antennas show a great resemblance to that of the wire version log-spiral structures.

The radiation patterns and the input impedances of a biangualr spiral structure were recorded. They show very small variation, both in the radiation pattern and the input impedances, for a very wide range of frequencies. The structure, $\theta_o = 7.5^\circ$, $\alpha = 73^\circ$ is shown in Figure 14.

Results of the measurements taken on these antennas are shown in the following sections.

4.2 Results of Measurement -- The Rectangular Spiral Antennas

4.2.1 Pattern Comparisons and the Comparison of the Axial Ratio

In order to show the similarity between the operation characteristics of the conical rectangular spiral antennas and that of the corresponding log-spiral antennas, the radiation patterns of these two types of antennas are

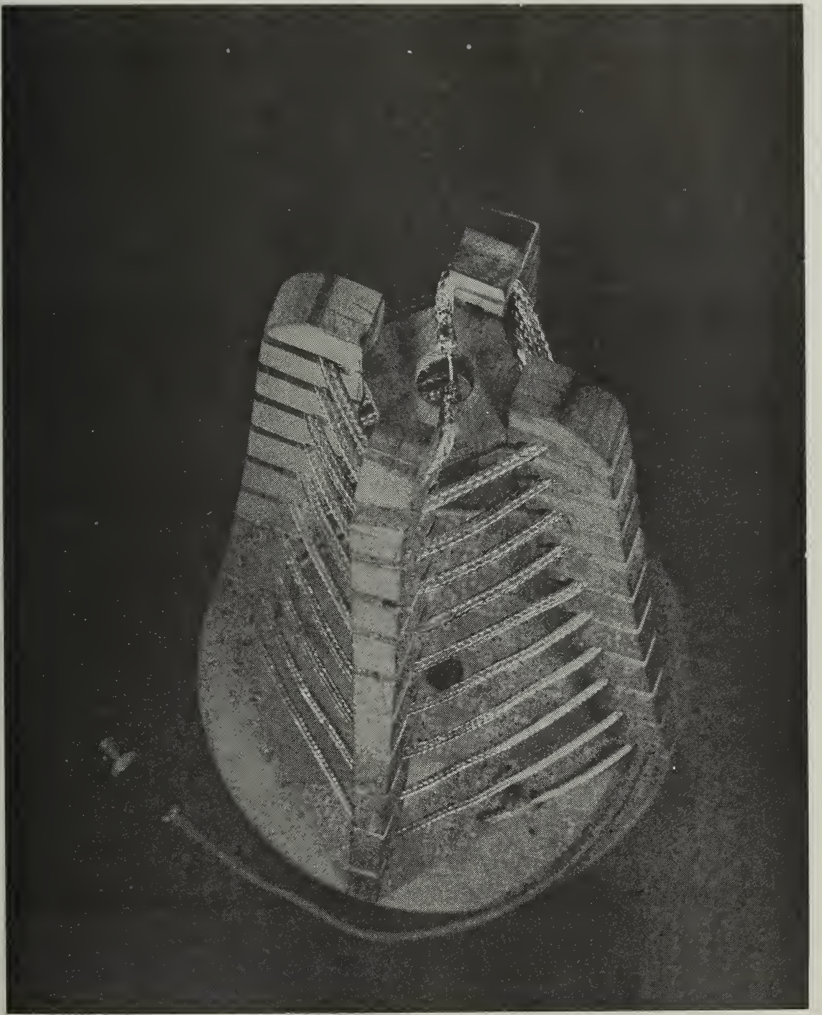

Figure 12. A Conical Rectangular Spiral Antenna

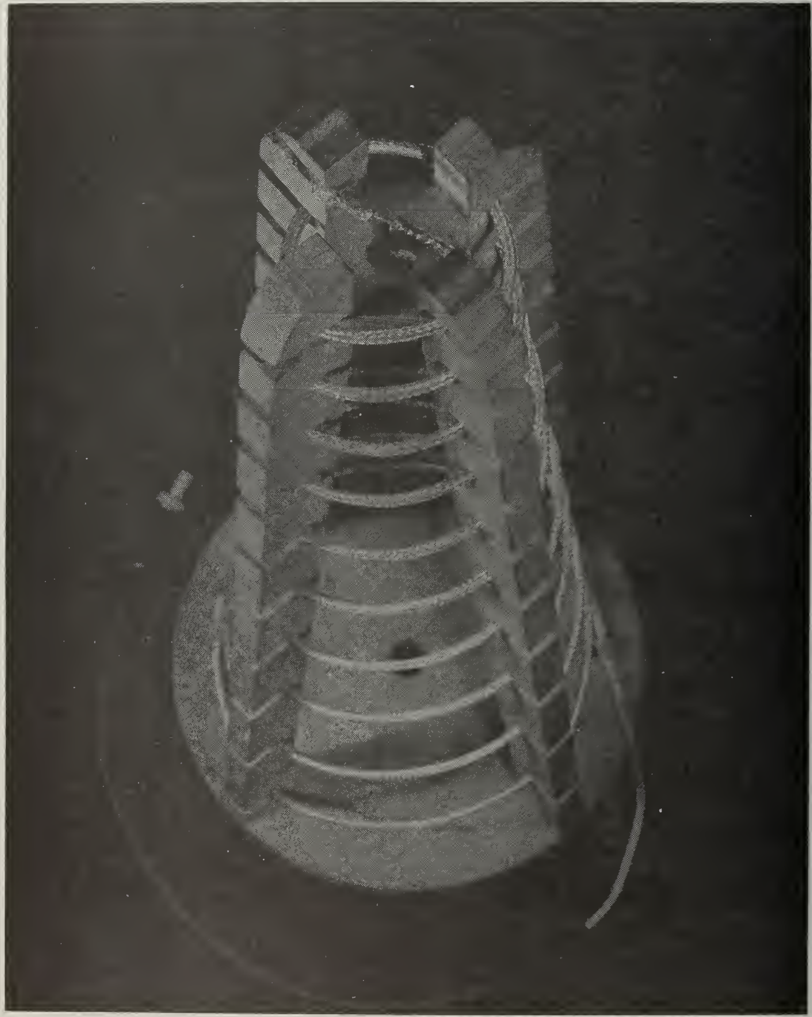

Figure 13. A Conical Log-Spiral Antenna

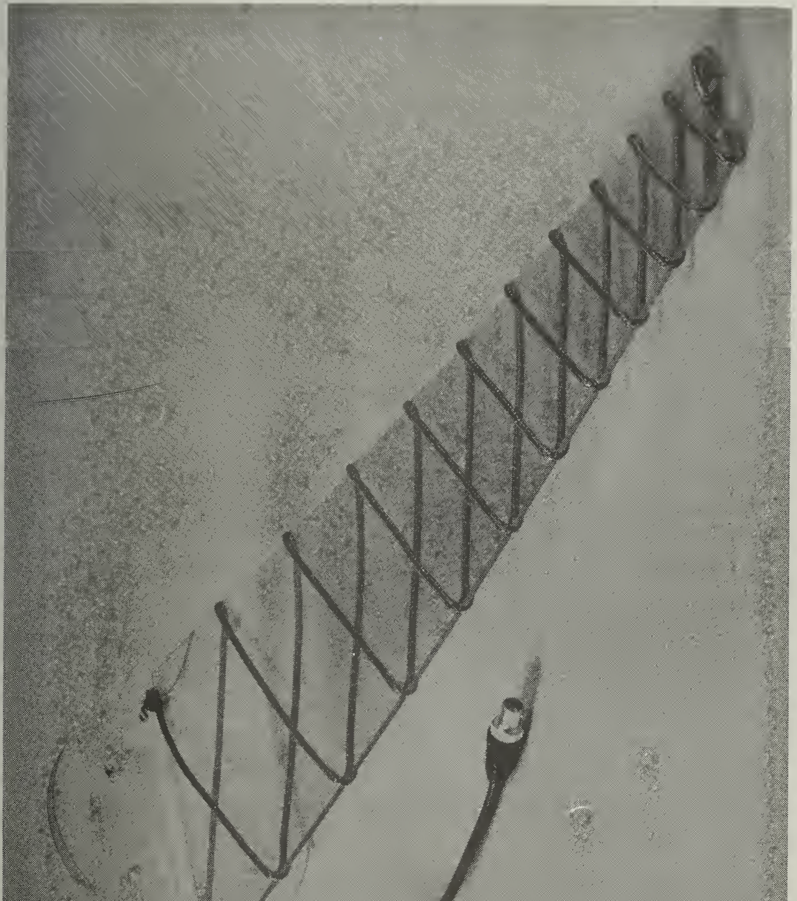

Figure 14. A Log-Spiral Zigzag Antenna

first compared for a range of frequencies. In the subsequent figures, the radiation patterns for the conical log-spiral antennas of the wire version are shown by solid lines while those for the conical rectangular spiral are shown by dotted lines. The following list gives the correspondence between the antenna patterns and the parameter of the antenna structures.

Figure 15	$\alpha = 73^\circ$	$\theta_o = 7.5^\circ$
Figure 16	$\alpha = 73^\circ$	$\theta_o = 10^\circ$
Figure 17	$\alpha = 60^\circ$	$\theta_o = 7.5^\circ$
Figure 18	$\alpha = 60^\circ$	$\theta = 10^\circ$
Figure 19	$\alpha = 45^\circ$	$\theta = 7.5^\circ$
Figure 20	$\alpha = 45^\circ$	$\theta = 10^\circ$

In each figure the patterns are shown both for $\phi = 0^\circ$ plane and for $\phi = 90^\circ$ plane, where ϕ angle is referred to the line determined by the feeding points.

The resemblance of the radiation patterns of these two types of antennas is apparant as seen from the figures. In many cases they are actually identical. For $\alpha = 73^\circ$, the patterns are unidirectional. The difference in the patterns of these two type of antennas is very small. As the spiral angle α decreases the beam width of the pattern increases. Although the difference for these patterns is somewhat larger in the cases for $\alpha = 60^\circ$ and $\alpha = 45^\circ$, there is no difficulty in pointing out their similarities. In the case of $\alpha = 45^\circ$, the wire version log-spiral structures fail to approximate the exact log-spiral antennas. The similar effect of multilobing exists in both the pattern of the wire log spiral structure and that of the corresponding rectangular spiral antenna.

The axial ratio of the polarization ellipsis are determined a) as a function of frequency for the polarization ellipsis of the electric fields measured on the antenna axis and b) as a function of the angle θ, where θ is the angle between the axis and a radial vector, drawn in $\phi = 0$ plane and the operating frequency in these cases is 700 Mc.

The axial ratios as a function of frequency are shown in Figure 21 through Figure 24. The following list gives the corresponding parameters of the structures.

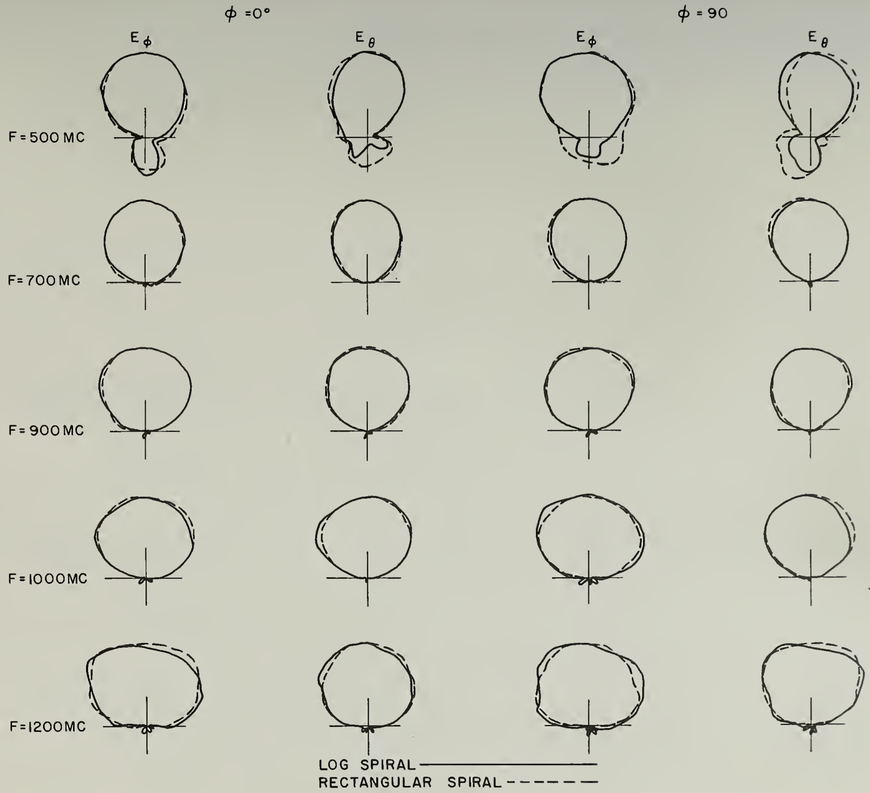

Figure 15. Pattern Comparison ($\theta_o = 7.5^o$, $\alpha = 73^o$)

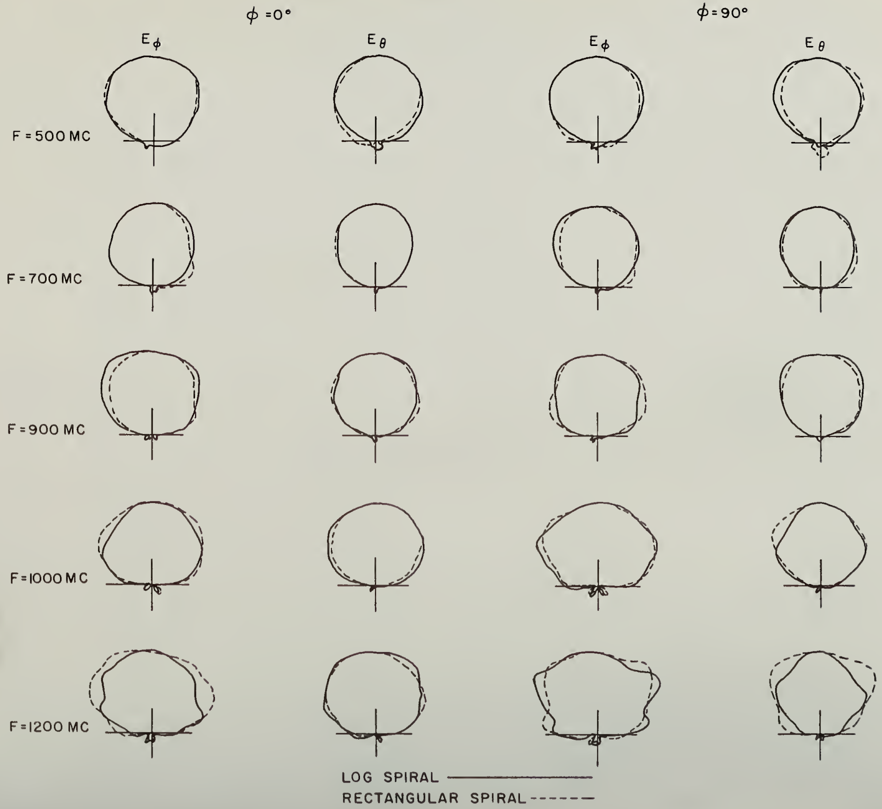

Figure 16. Pattern Comparison ($\theta_o = 10^o$, $a = 73^o$)

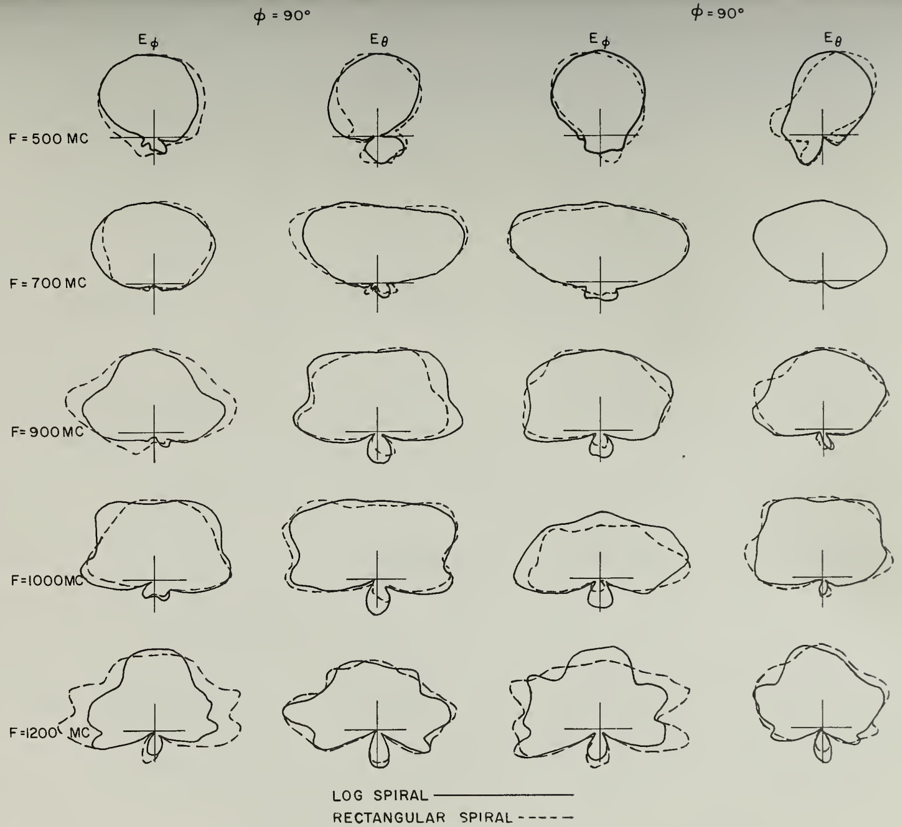

Figure 17. Pattern Comparison ($\theta_o = 7.5^o$, $a = 60^o$)

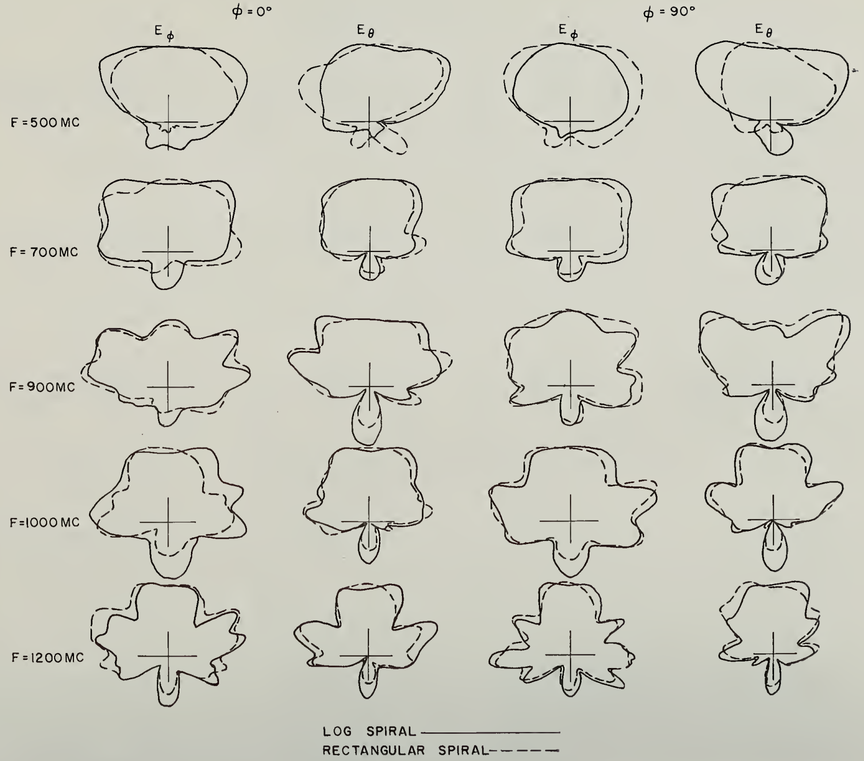

Figure 18. Pattern Comparison ($\theta_o = 10^o$, $a = 60^o$)

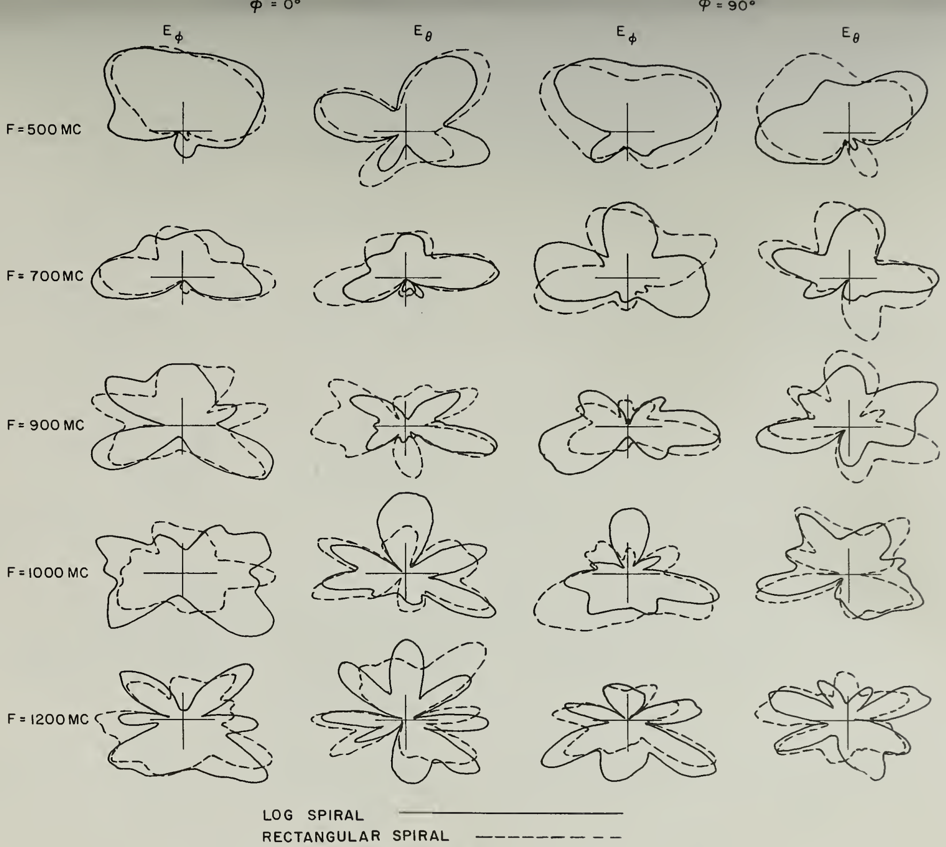

Figure 19. Pattern Comparison ($\theta_o = 7.5^o$, $a = 45^o$)

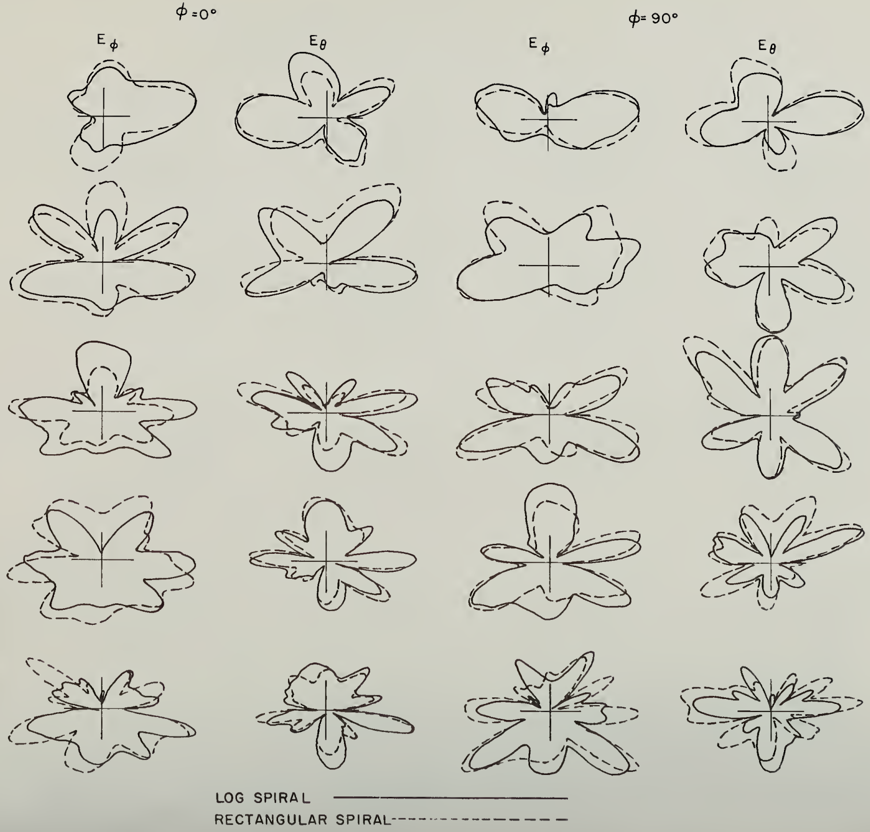

Figure 20. Pattern Comparison ($\theta_o = 10^o$, $a = 45^o$)

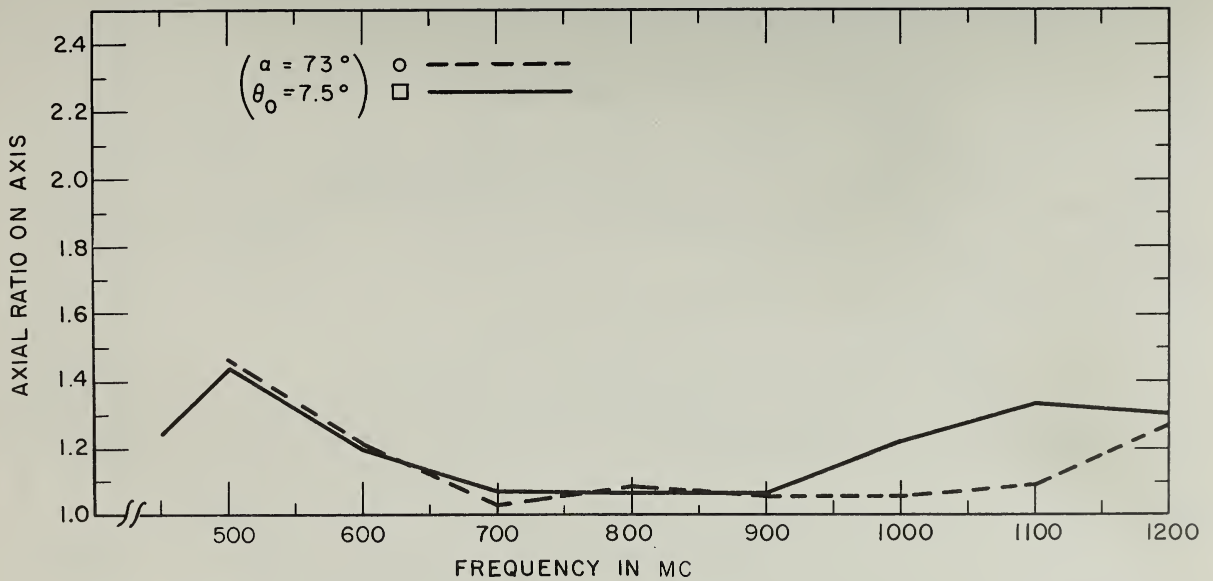

Figure 21. Comparison of the Axial Ratio - As a Function of the Frequency

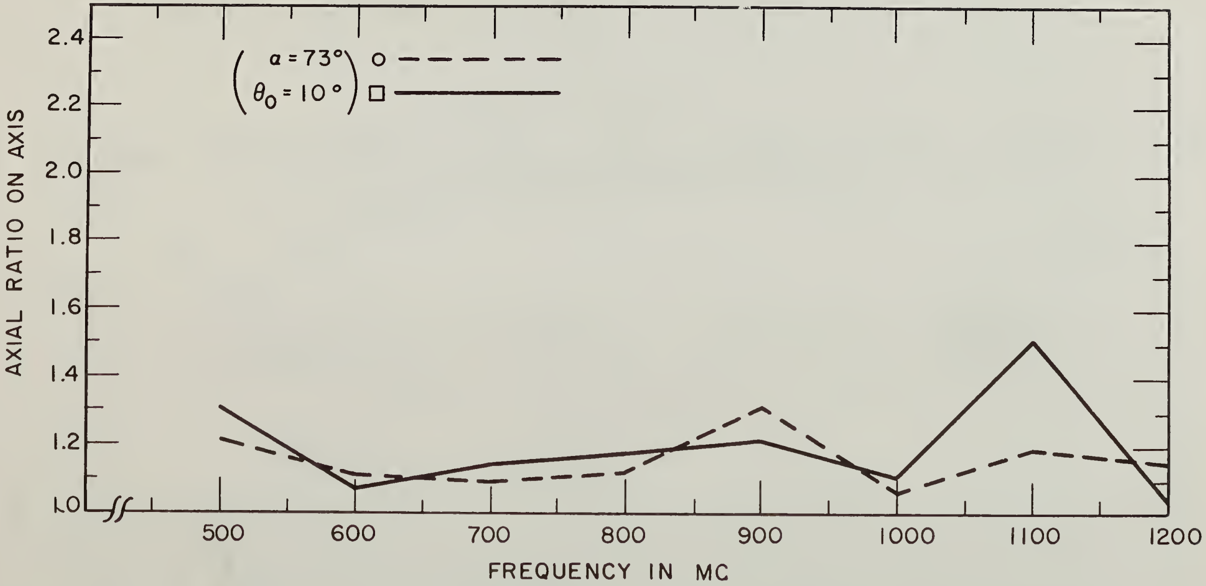

Figure 22. Comparison of the Axial Ratio - As a Function of the Frequency

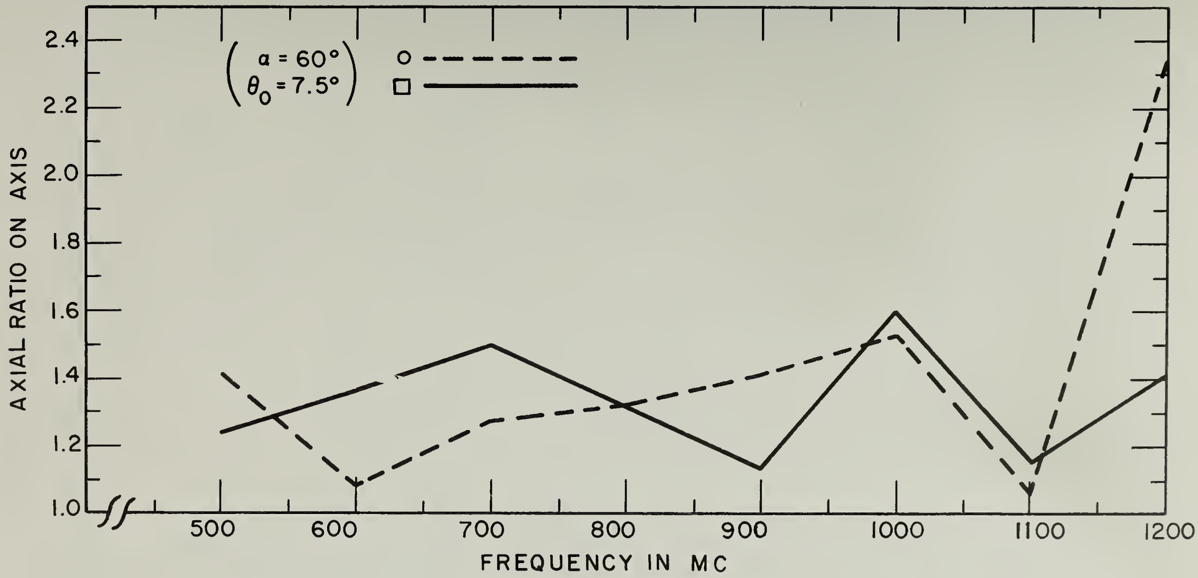

Figure 23. Comparison of the Axial Ratio - As a Function of the Frequency

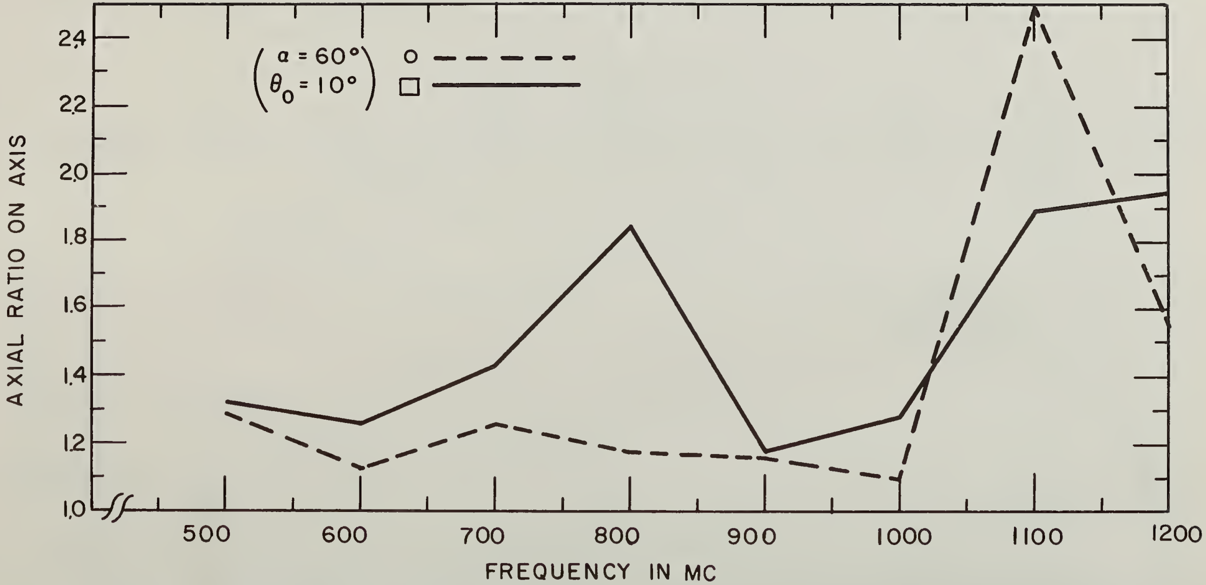

Figure 24. Comparison of the Axial Ratio - As a Function of the Frequency

Figure 21	$\alpha = 73^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 22	$\alpha = 73^{\circ}$	$\theta_o = 10^{\circ}$
Figure 23	$\alpha = 60^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 24	$\alpha = 60^{\circ}$	$\theta_o = 10^{\circ}$

The axial ratios as a function of the angle θ are shown in Figures 25 through 28. The corresponding parameters of the structures are

Figure 25	$\alpha = 73^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 26	$\alpha = 73^{\circ}$	$\theta_o = 10^{\circ}$
Figure 27	$\alpha = 60^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 28	$\alpha = 60^{\circ}$	$\theta_o = 10^{\circ}$

In each of these figures, the axial ratios of the corresponding log-spiral structure are accompanied in dotted lines. These experimental results again give the following two indications.

(a) The frequency independent operation of the conical rectangular spiral antenna

(b) The closeness in the performances of the rectangular spiral antenna and of the log-spiral antennas.

4.2.2 The Standing Wave Ratio and The Input Impedance

The standing wave ratios of these rectangular spiral structures are shown in Figures 29 through 34 in comparison with that of the log-spiral structures (dotted lines). The parameters of the antenna structures for the set of data are indicated in the following list.

Figure 29	$\alpha = 73^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 30	$\alpha = 73^{\circ}$	$\theta_o = 10^{\circ}$
Figure 31	$\alpha = 60^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 32	$\alpha = 60^{\circ}$	$\theta_o = 10^{\circ}$
Figure 33	$\alpha = 45^{\circ}$	$\theta_o = 7.5^{\circ}$
Figure 34	$\alpha = 45^{\circ}$	$\theta_o = 10^{\circ}$

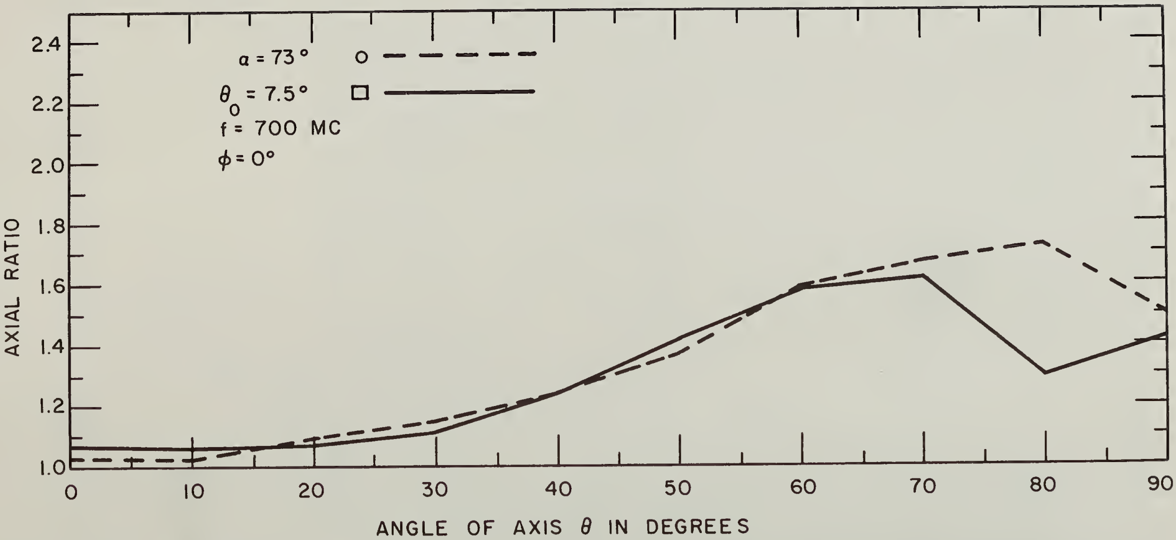

Figure 25. Comparison of the Axial Ratio - As a Function of the Elevation Angle θ

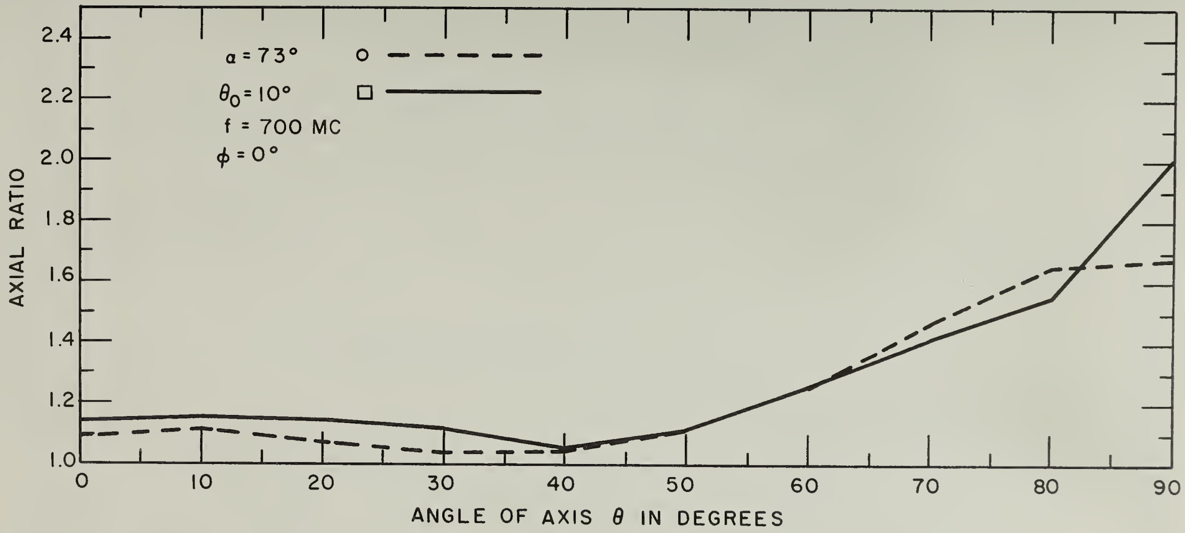

Figure 26. Comparison of the Axial Ratio - As a Function of the Elevation Angle θ

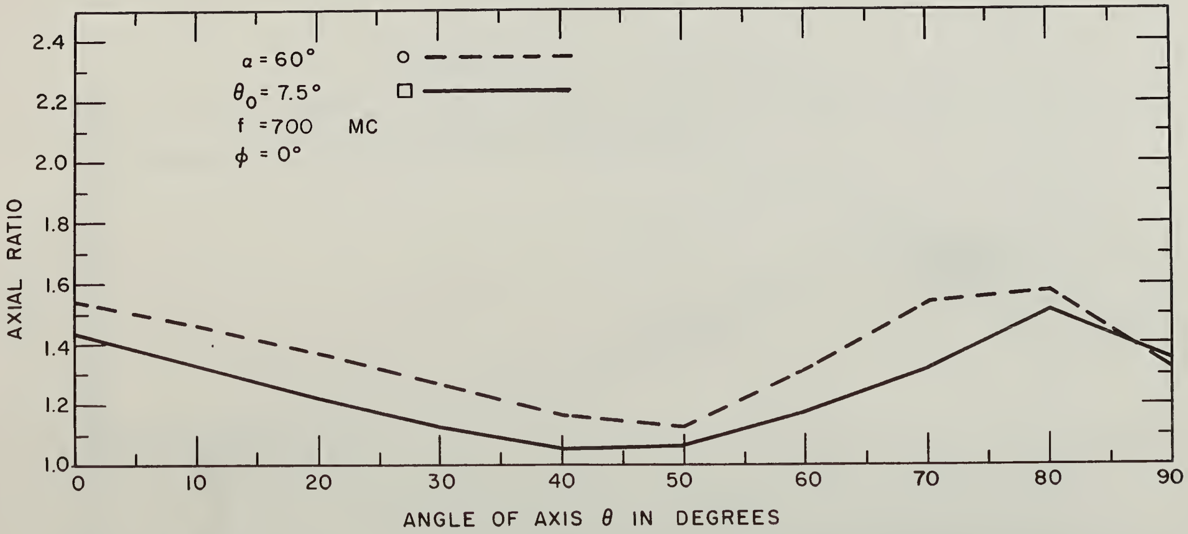

Figure 27. Comparison of the Axial Ratio - As a Function of the Elevation Angle θ

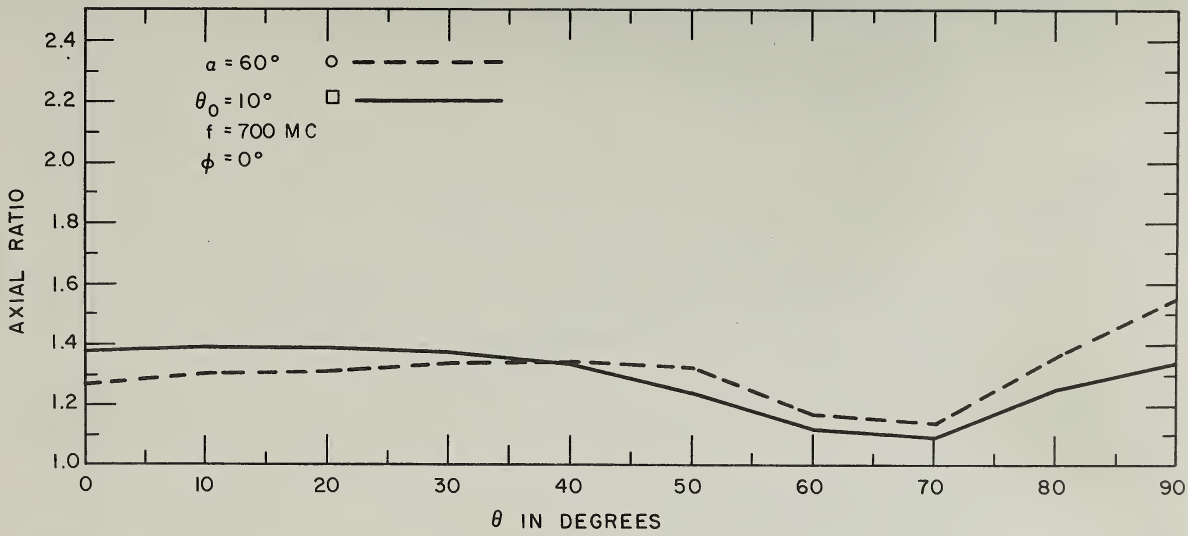

Figure 28. Comparison of the Axial Ratio - As a Function of the Elevation Angle θ

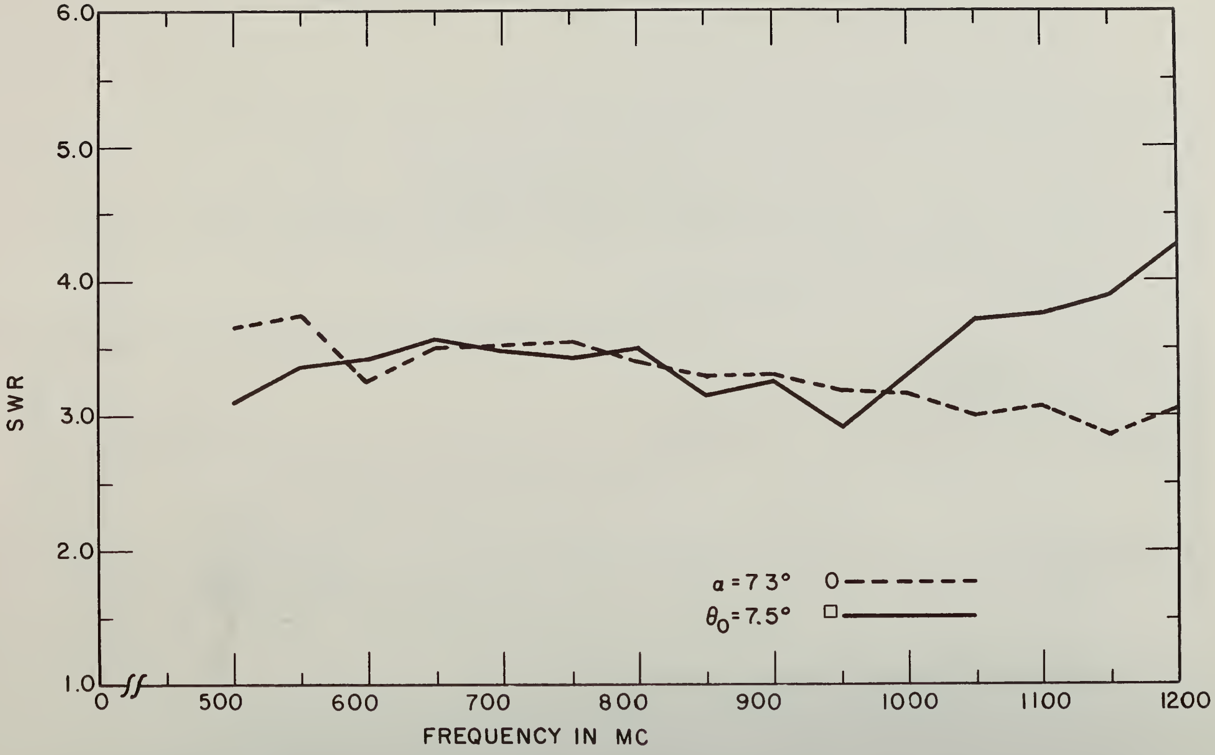

Figure 29. Comparison of the Standing Wave Ratio

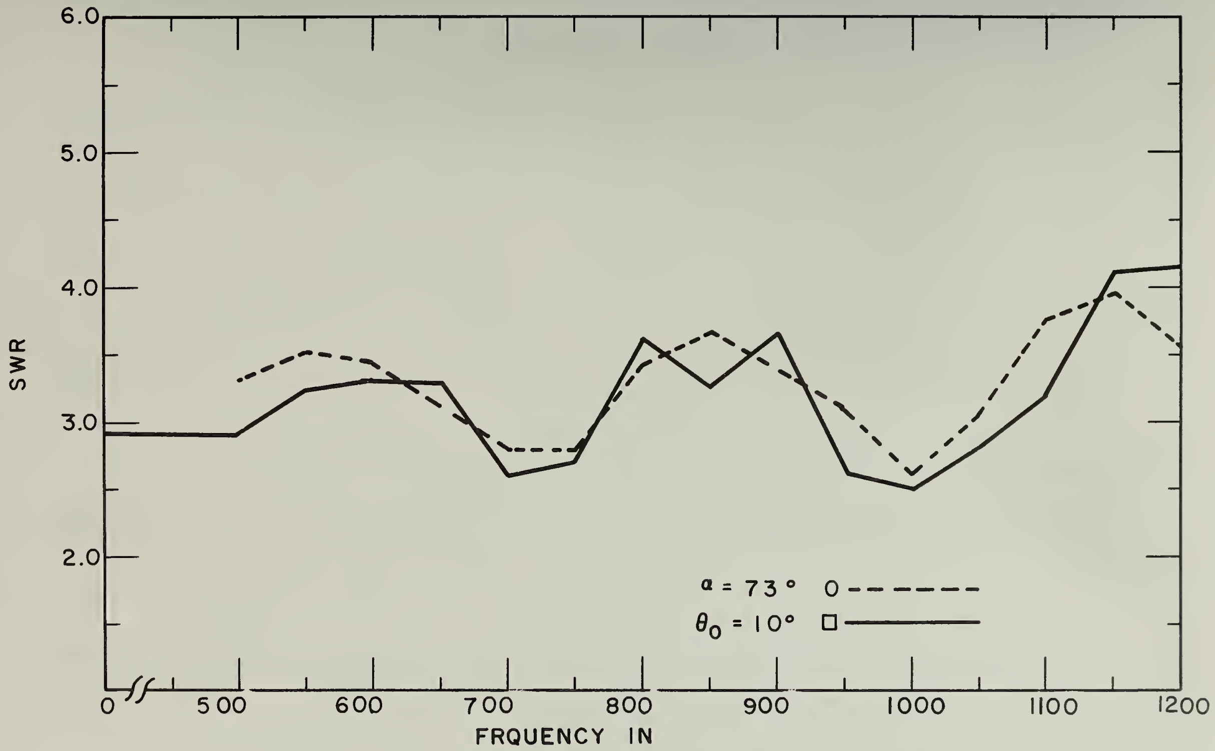

Figure 30. Comparison of the Standing Wave Ratio

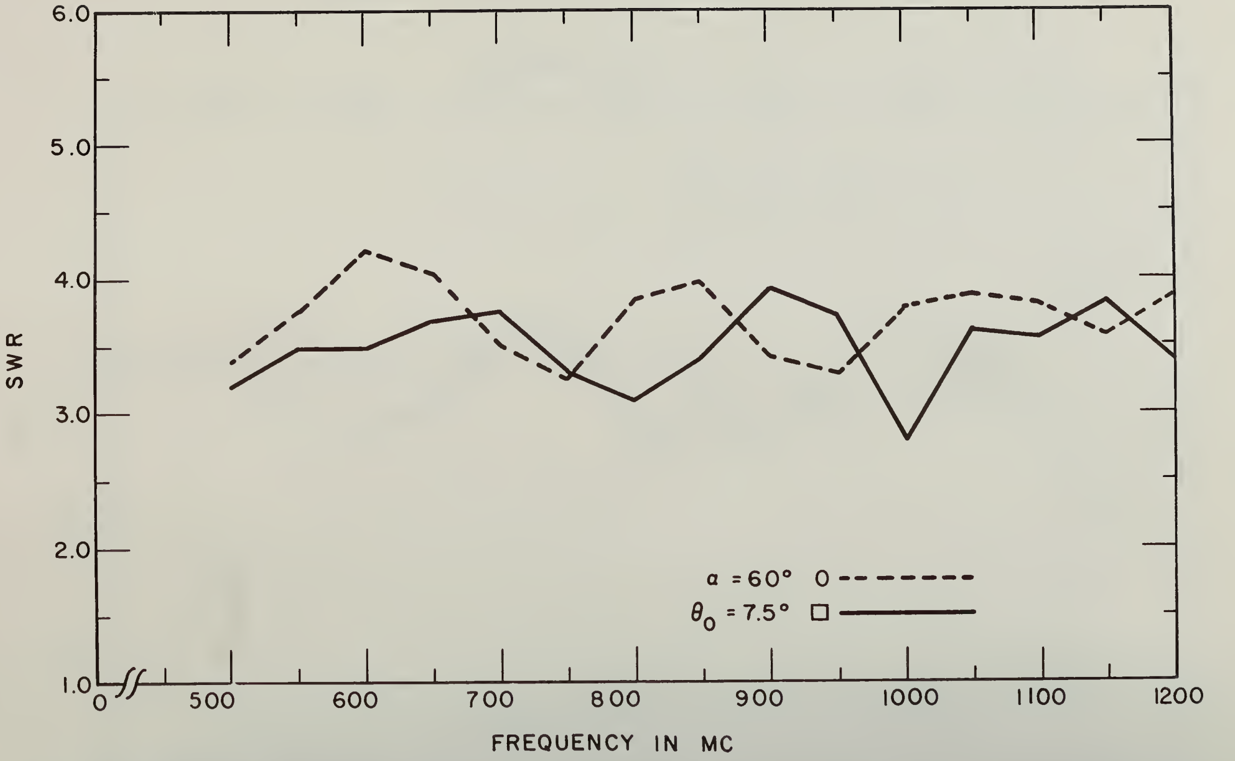

Figure 31. Comparison of the Standing Wave Ratio

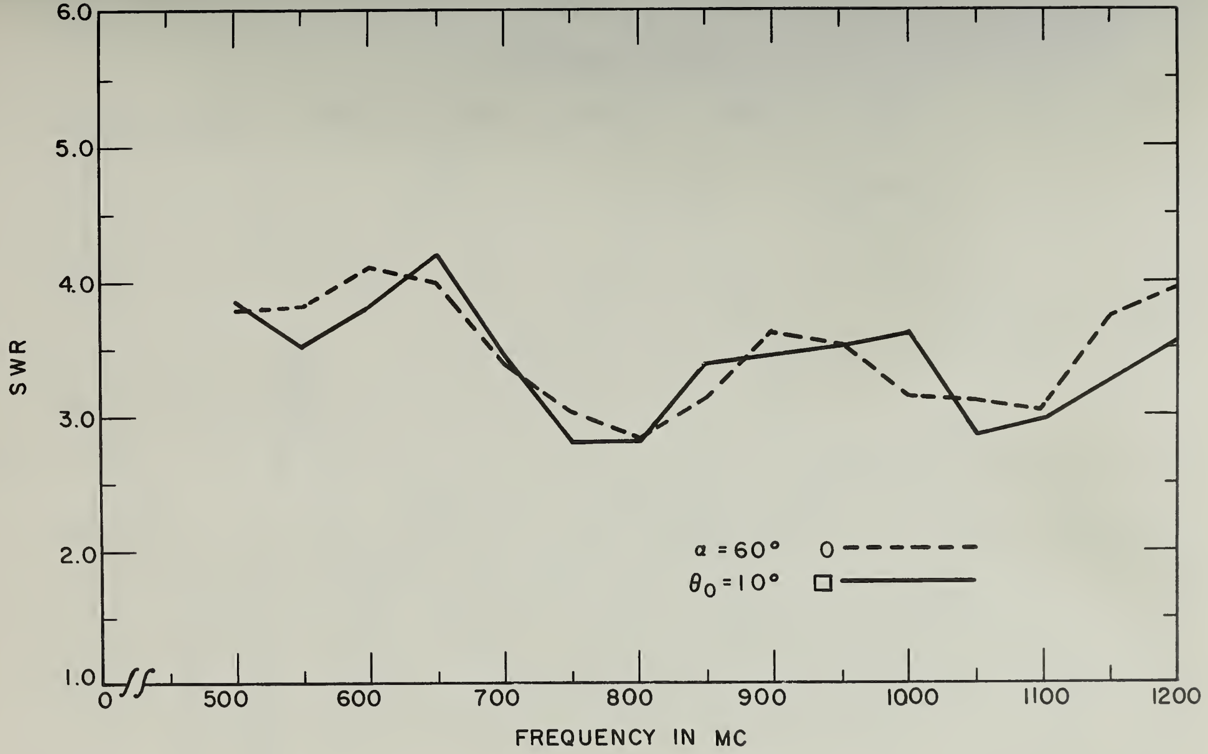

Figure 32. Comparison of the Standing Wave Ratio

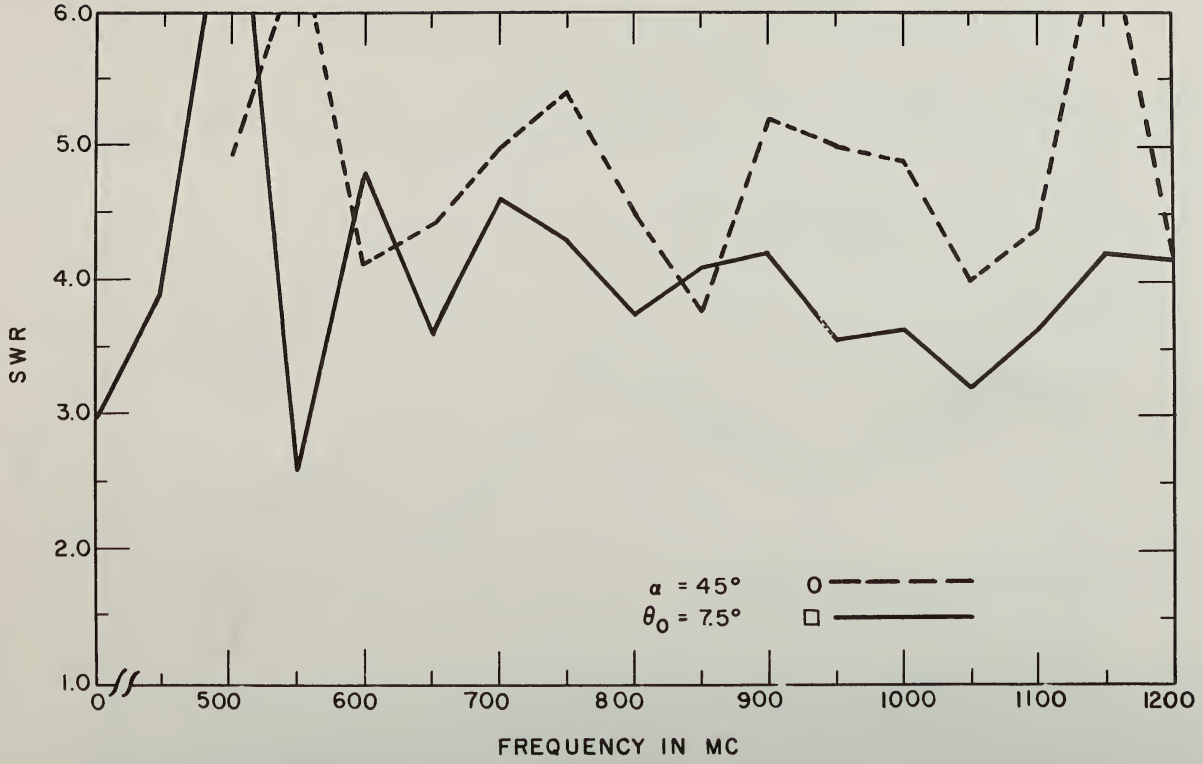

Figure 33. Comparison of the Standing Wave Ratio

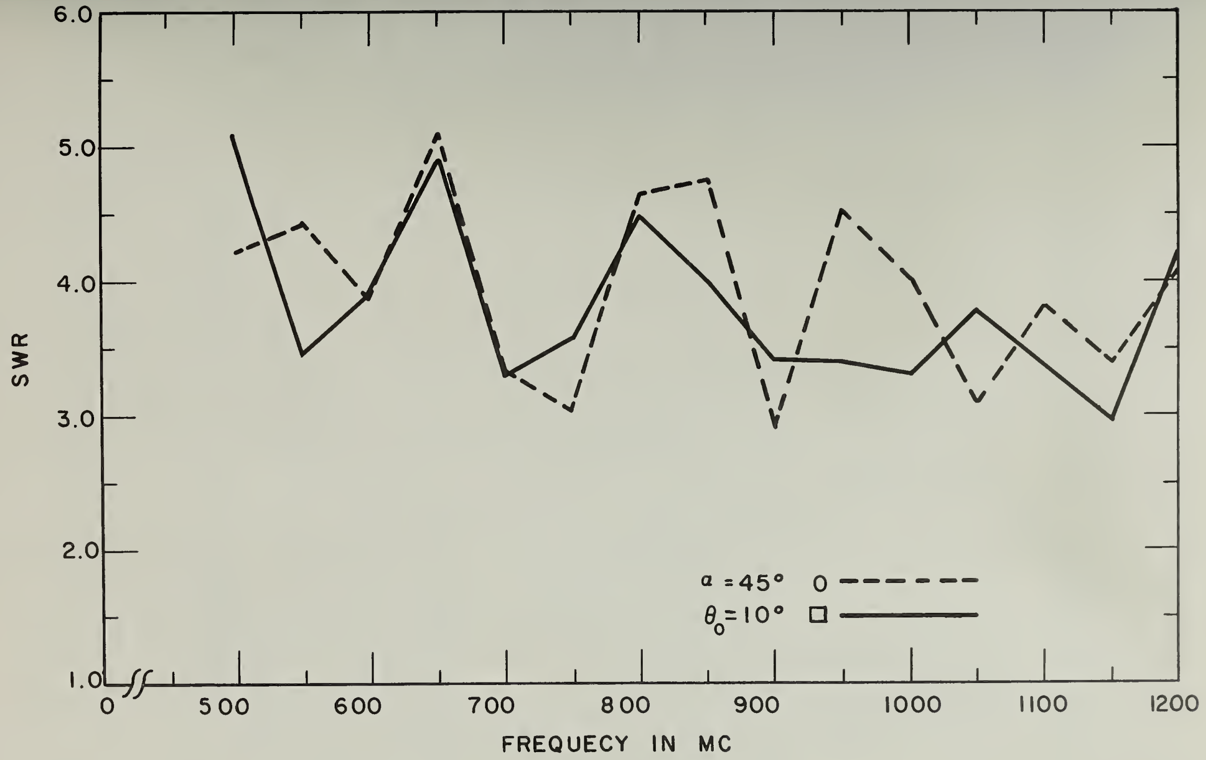

Figure 34. Comparison of the Standing Wave Ratio

The input impedances of these antennas have also been determined. They are shown in Figures 35 through 40 in comparison with those values for the log-spiral antennas. The correspondence of the parameters of the antenna structures and their figures are in the same sequence as before, namely;

Figure 35 $\alpha = 73^\circ$ $\theta_o = 7.5^\circ$
Figure 36 $\alpha = 73^\circ$ $\theta_o = 10^\circ$
Figure 37 $\alpha = 60^\circ$ $\theta_o = 7.5^\circ$
Figure 38 $\alpha = 60^\circ$ $\theta_o = 10^\circ$
Figure 39 $\alpha = 45^\circ$ $\theta_o = 7.5^\circ$
Figure 40 $\alpha = 45^\circ$ $\theta_o = 10^\circ$

These experimental results again indicate the practibility of the rectangular spiral structure used as a frequency independent antenna.

4.3 Results of Measurements -- The Biangular Spiral Antenna

Since a log periodic Zigzag antenna is a biangular spiral antenna which is just a special case of the polygonal spiral antenna, it is expected that it should also possess the frequency independent characteristics which were defined earlier. To confirm this fact, a log-periodic zigzag antenna was built (Figure 14) and its characteristics determined. The results are shown below.

4.3.1 Radiation Patterns

The radiation patterns are taken for a range of frequencies (600 ~ 1500 Mc), both for the E-plane and the H-plane. The variations, as shown in Figure 41, are small within this frequency range.

Note that for this type of structure, the radiation pattern is linearly polarized, while those of other polygonal spiral antennas are expected to be circularly polarized.

4.3.2 The Standing Wave Ratio and the Input Impedance

The standing wave ratio measured for the antenna is shown in Figure 42, while the input impedance is given in Figure 43. It is seen that the variations which existed in these results over a wide range of frequencies (500 ~ 1400 Mc) are small. It thus shows the applicability of this structure for the frequency independent operation.

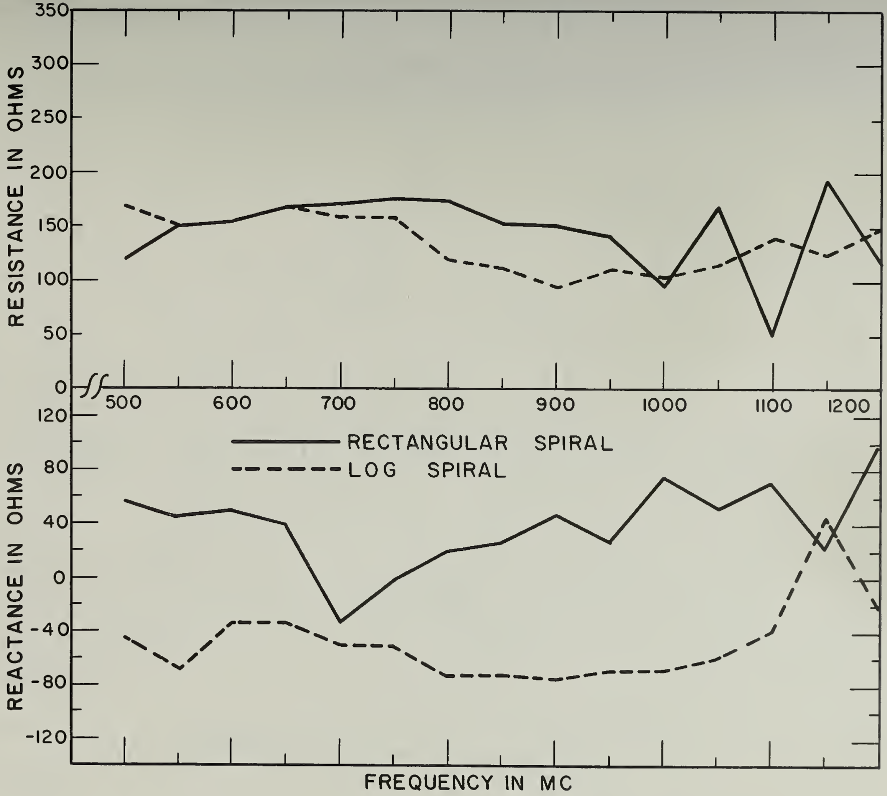

Figure 35. Comparison of the Input Impedance ($\theta_o = 7.5^\circ$, $\alpha = 73^\circ$)

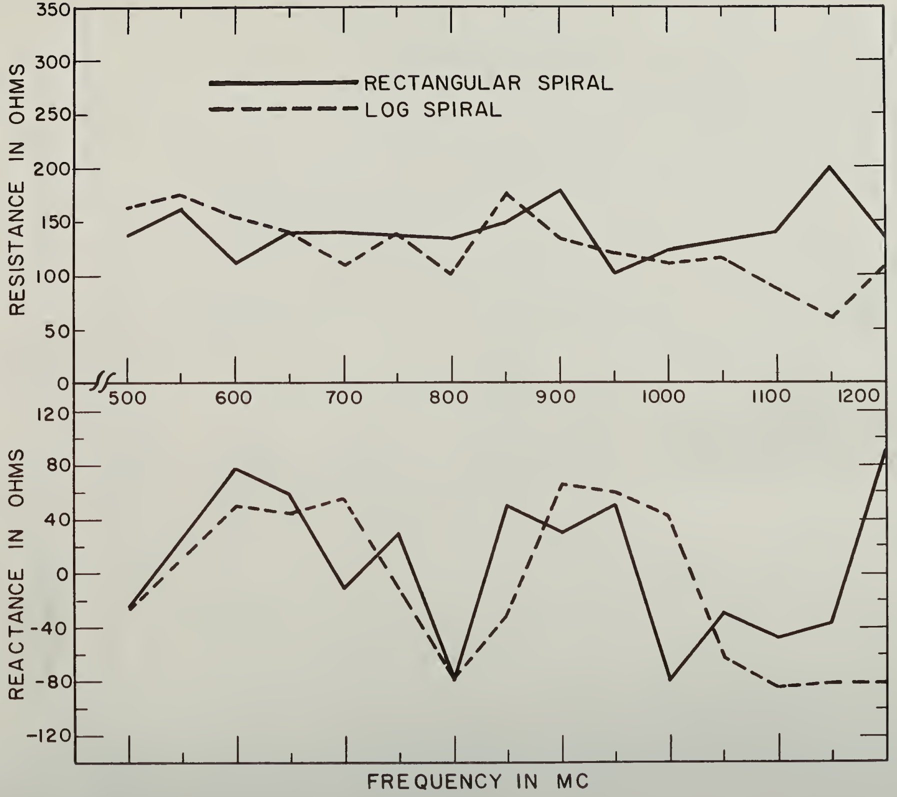

Figure 36. Comparison of the Input Impedance $(\theta_o = 10^\circ, a = 73^\circ)$

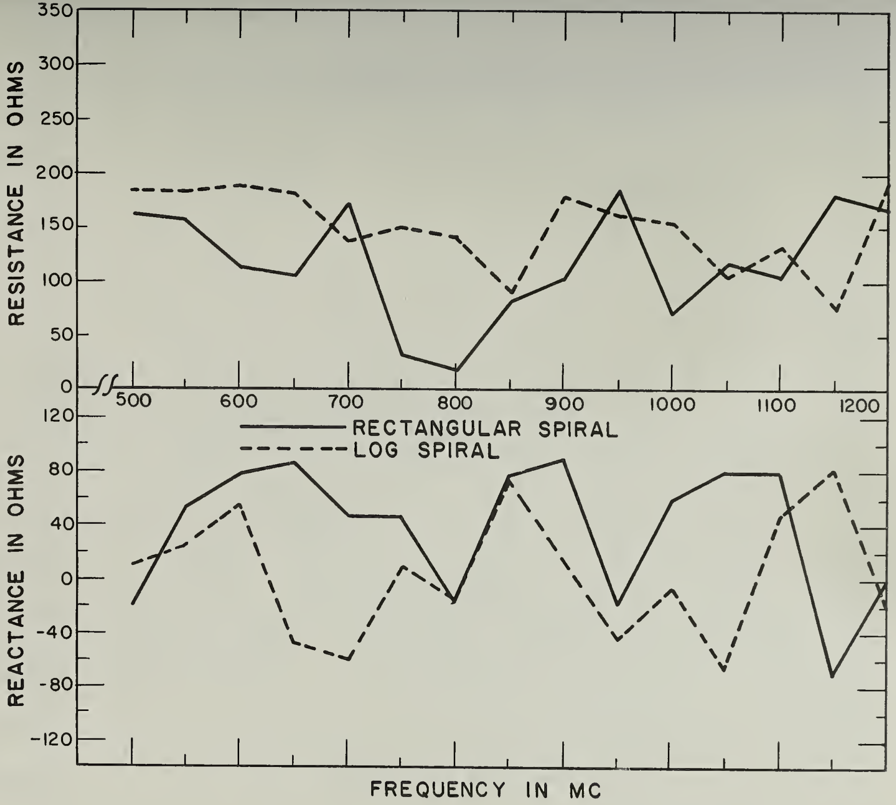

Figure 37. Comparison of the Input Impedance ($\theta_o = 7.5^o$, $a = 60^o$)

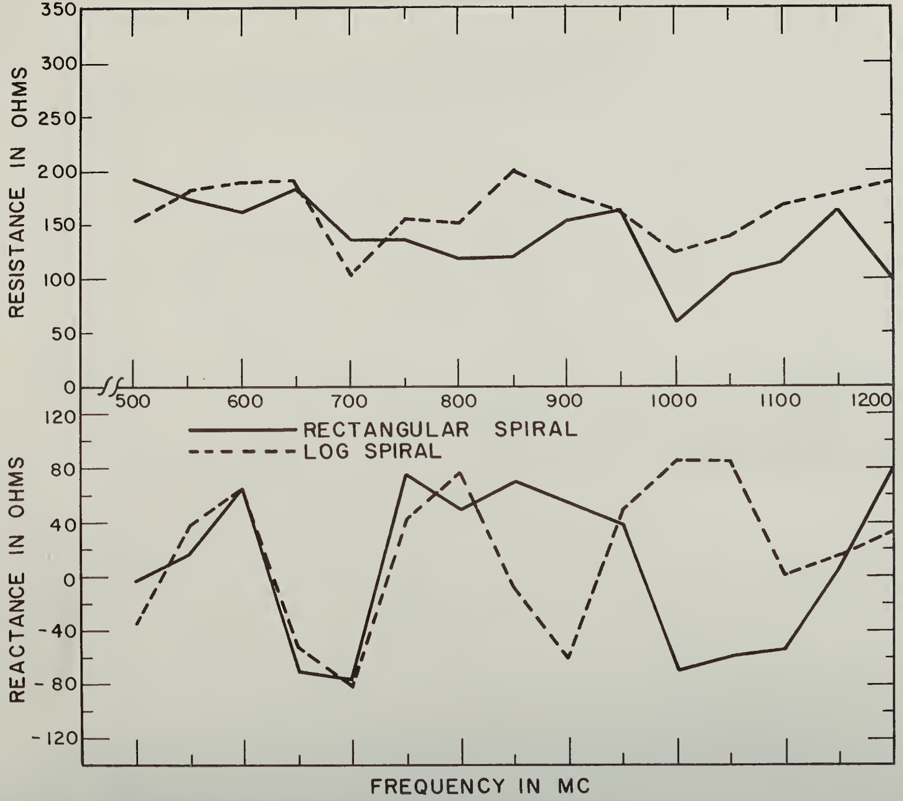

Figure 38. Comparison of the Input Impedance ($\theta_o = 10^o$, $a = 60^o$)

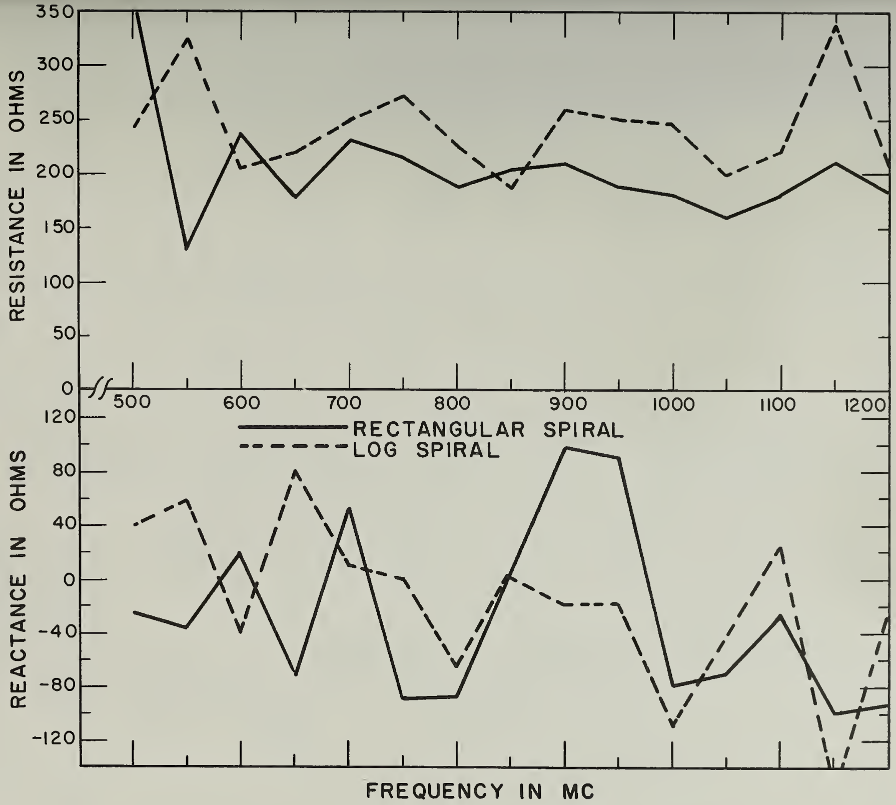

Figure 39. Comparison of the Input Impedance ($\theta_o = 7.5^o$, $a = 45^o$)

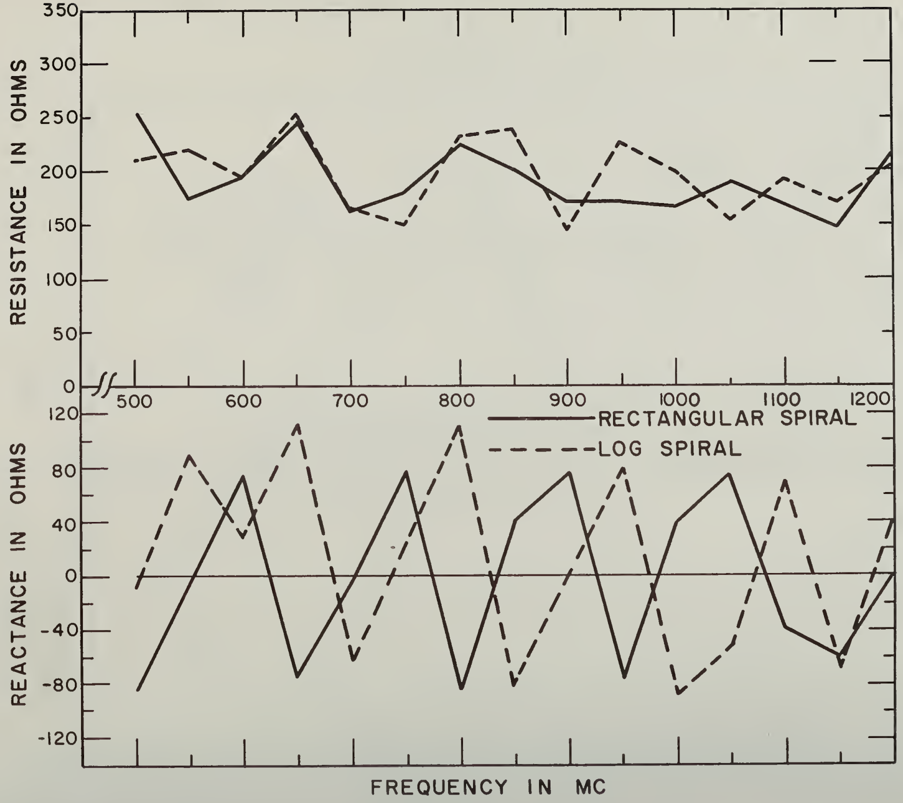

Figure 40. Comparison of the Input Impedance ($\theta_o = 10^\circ$, $a = 45^\circ$)

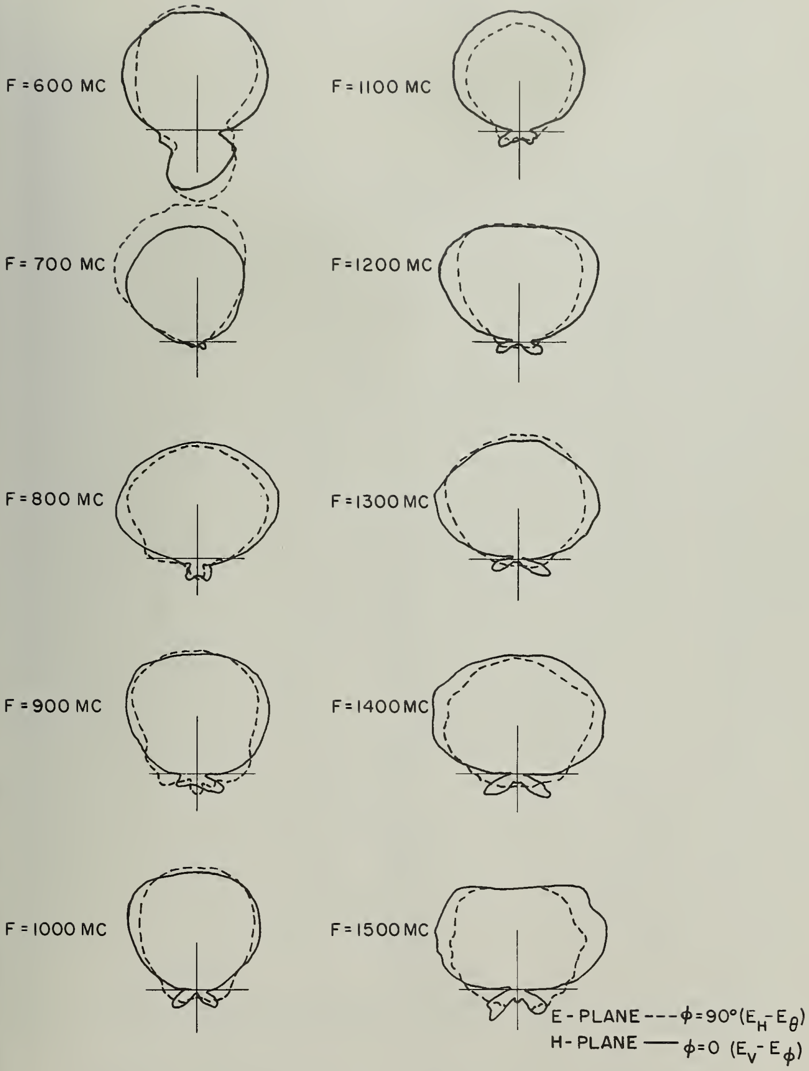

Figure 41. Radiation Patterns of the Log-Periodic Zigzag Antenna ($\theta_o = 7.5^o$, $\alpha = 73^o$).

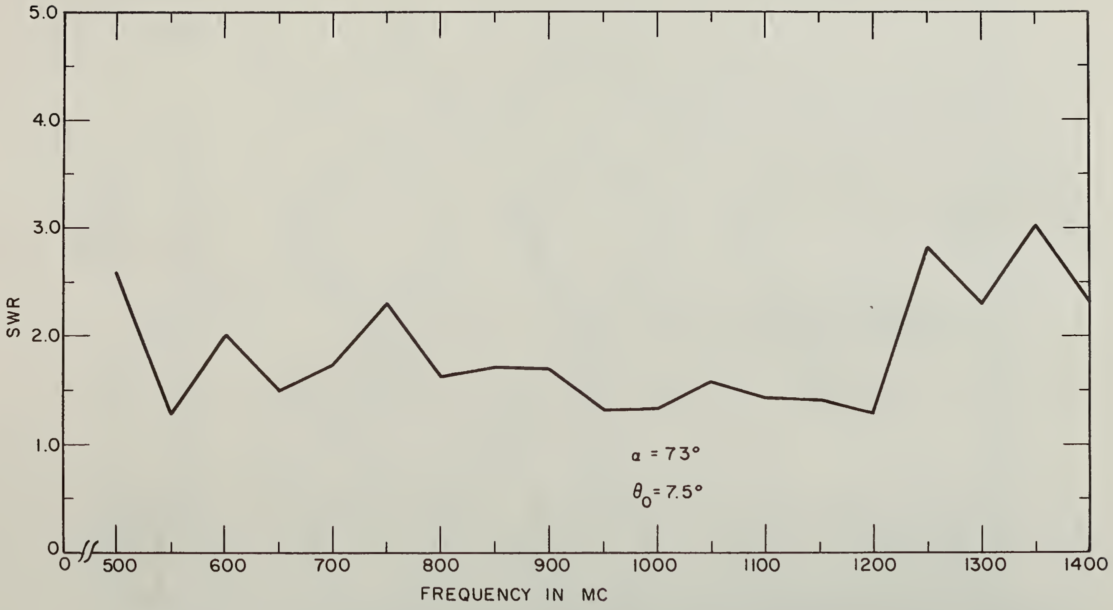

Figure 42. The Standing Wave Ratio of the Log-Periodic Zigzag Antenna ($\theta_o = 7.5^o$, $\alpha = 73^o$)

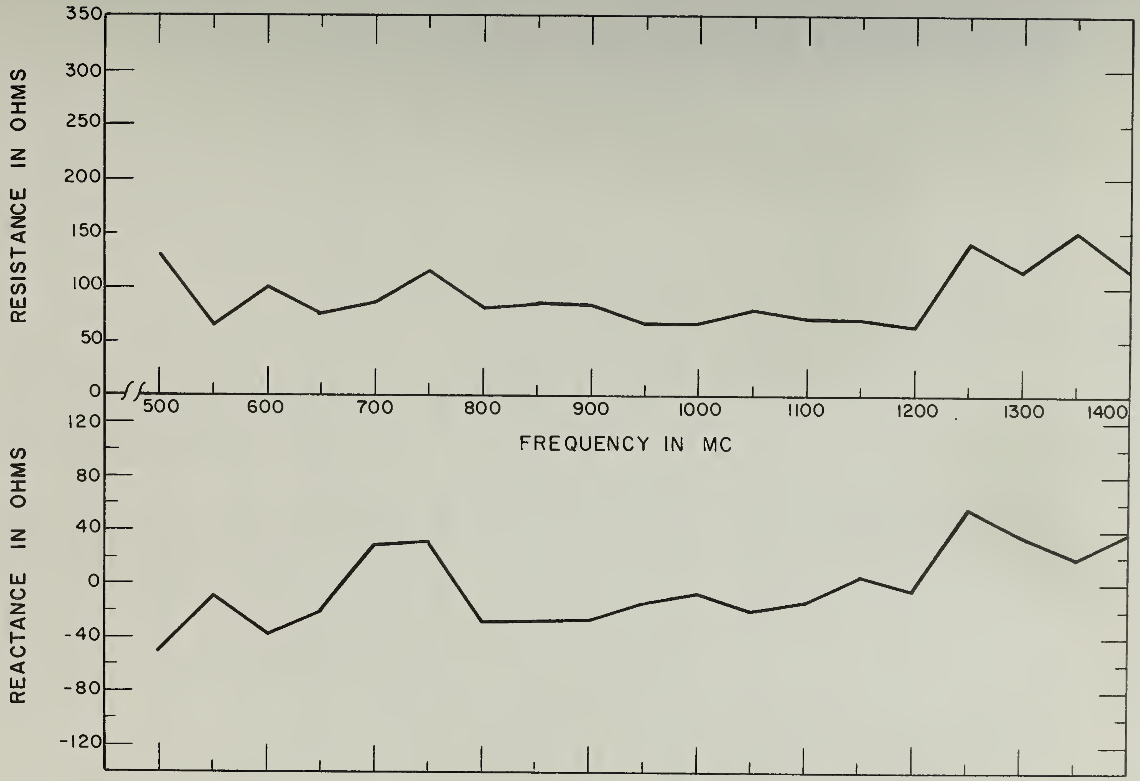

Figure 43. The Input Impedance of the Log-Periodic Zigzag Antenna ($\theta_o = 7.5^o$, $\alpha = 73^o$)

5. CONCLUSIONS

In this report, limited literature on the problem of the frequency independent antennas is reviewed. It is felt that although the complete theoretical solution of the problem is not yet available, the antenna engineer can make progress in the practical design, based on the basic principle of scaling. The main idea suggested was the relaxation of the similarity condition on the rigorous angular structures. This has been one of the design methods in the development of the log-periodic antennas. The method was used to modify the log-spiral antennas. It is hoped that through an accumulation of workable structures theoreticans may have a better idea in making assumptions for the solution of the problem.

The construction of the polygonal spiral antennas was given in terms of the construction of the polygonal spiral curve. Through the construction the relation between the structure with the continuous similarity condition and that with discrete similarity condition was demonstrated. The experimental method was used in determining the applicability of the polygonal spiral structure for the use of the frequency independent antenna.

The measurement results showed that the rectangular spiral antenna is a good approximation to the log-spiral antenna, for two equivalent antennas of these types behave practically the same, as far as the frequency independent operation is concerned.

The measurements for a bifilar log-periodic Zigzag antenna, a special case of the polygonal spiral antenna, were performed for a range of frequencies and results given. The frequency independent operation of this type of antennas was also indicated.

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